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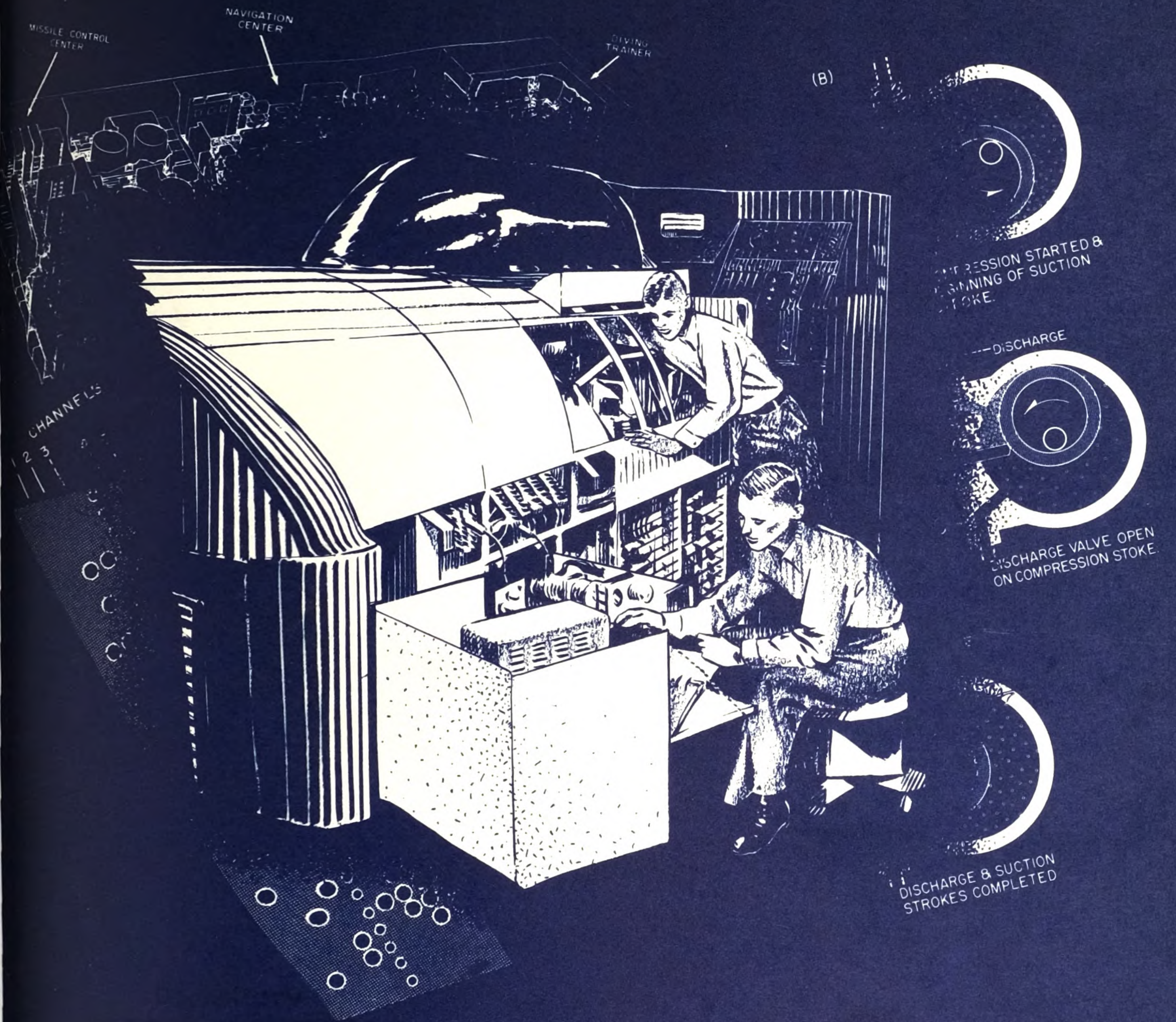

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TRADEVMAN 1 & C

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10378-A

PREFACE

This Navy Training Course is one of a series of training courses prepared especially for enlisted personnel of the U.S. Navy and Naval Reserve who are studying for advancement in the Tradevman (TD) rating. It is based on the qualifications for the rates of TD1 and TDC as contained in the Manual of Qualifications for Advancement in Rating, NavPers 18068-A.

The chapters of this training course should be studied in conjunction with supplementary material provided in several basic courses. It would behoove the Tradevman to carefully study the reading list and use the material recommended there in conjunction with this course.

This training course was prepared by the U.S. Navy Training Publications Center, Memphis, Tennessee, for the Bureau of Naval Personnel. Credit is hereby given to the Tradevman School, Memphis, Tennessee, and the U.S. Naval Training Device Center for technical assistance.

1964 edition

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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MAIN LIBRARY

READING LIST

NAVY TRAINING COURSES

Basic Electricity, NavPers 10086-A

Basic Electronics, NavPers 10087-A

Basic Handtools, NavPers 10085-A

Basic Machines, NavPers 10624

Blueprint Reading and Sketching, NavPers 10077-B

Tradevman 3 & 2, NavPers 10376-A

OTHER PUBLICATIONS

Basic Hydraulics, NavPers 16193

Manual for Navy Instructors, NavPers 16103-B

Aerodynamics for Naval Aviators, NavWeps 00-80T-80

CHAPTER 1

THE TRADEVMAN RATING

This course is written to aid the TD2 or TD1 in preparing for advancement to TD1 or Chief TD, respectively. There are many requirements for advancement in rating and they are discussed later in this chapter. This training course deals primarily with the professional requirements or qualifications for TD1 and Chief as listed in the 1963 revision of the Manual of Qualifications for Advancement in Rating (NavPers 18068-A). Any changes in qualifications occurring after the revision may not be reflected in the information given in this course.

Military requirements are discussed in the current edition of Basic Military Requirements (NavPers 10054-A), Military Requirements for Petty Officers 3 & 2 (NavPers 10056-A), and Military Requirements for Petty Officers 1 & C (NavPers 10057-A).

Chapter 2 presents information concerning the various records and reports required for training equipment. It also provides information on ordering devices, maintenance equipment, and spare parts.

Chapter 3 continues the discussion of administering the training device activity with information relative to maintaining the equipment with maintenance personnel.

Chapter 4 presents a description of the test equipment used in the maintenance of trainers.

Chapters 5 and 6 contain the principles of air conditioning with applications to air conditioners used with training equipment.

Chapters 7 and 8 concern the principles of television with specific application to closed circuit television used with training devices.

Chapter 9 presents the principles of magnetic amplifiers.

Chapter 10, 11, and 12 contain descriptions of analog and digital computers. Chapter 12 specifically provides information for the maintenance of digital computers used in training equipment.

Chapter 13 provides descriptions of tactical trainers used to train individuals and crews to develop proficiency in their tactical mission.

The remainder of this chapter contains information that will help you in preparing for advancement. It is strongly recommended that you study this chapter carefully before beginning intensive study of the remainder of this training course.

THE ENLISTED RATING STRUCTURE

The present enlisted rating structure, established in 1957, includes three types of ratings: general ratings, service ratings, and emergency ratings.

GENERAL RATINGS are designed to provide paths of advancement and career development. A general rating identifies a broad occupational field of related duties and functions requiring similar aptitudes and qualifications. General ratings provide the primary means used to identify billet requirements and personnel qualifications. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Subdivisions of certain general ratings are identified as SERVICE RATINGS. These service ratings identify areas of specialization within the scope of a general rating. Service ratings are established in those general ratings in which specialization is essential for efficient utilization of personnel. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

EMERGENCY RATINGS identify essentially civilian occupations. Emergency ratings are not identified as ratings in the peacetime Navy, but their identification is required in time of war.

THE TD RATING

The Tradevmen rating is a general rating and is included in the Navy Occupational Aviation Group IX. This grouping, however, does not limit the assignment of Tradevmen to aviation activities; it only groups the ratings with the activities having primary interest in the training and performance of TD personnel.

The Manual of Qualifications for Advancement in Rating, NavPers 18068-A, states that Tradevmen are responsible for the installation, operation, repair, and maintenance of training devices. They must also instruct individuals and groups by means of lectures, demonstrations, and operation of training devices and related aids with particular emphasis on those circumstances which require the use of training devices to simulate operation conditions.

The TD1 must be qualified to supervise and direct trainer inspections; maintain logs and records and prepare reports; order and identify publications; maintain current shop files of directives and other publications; identify and order parts, tools, and equipment; maintain inventory records; use schematic diagrams, drawings, and charts in troubleshooting and correcting material failures.

In addition to the above listed requirements for TD1, the TDC must be qualified to review and evaluate completed inspection forms and reports; analyze reports of discrepancies and malfunctions and determine corrective action; schedule and assign workload; determine repair procedures for training devices; interpret directives from higher authorities; and maintain quality control of work performed.

A wide variety of assignments is available to the Tradevman. In addition to the various types of maintenance activities to which lower rated personnel are assigned, the TD1 and TDC are eligible for assignment to instructor duty as well as a number of other desirable billets. Most of these billets are under the management control of BuPers and are directly associated with training. Others are associated with research, testing, or evaluation. Some of the billets to which the TD1 and TDC may be assigned are described briefly as follows:

1. Fleet submarine and fleet ballistic missile submarine trainers: Operating and maintaining trainers used to train submarine crews. These trainers are located at New London, Connecticut; Charleston, South Carolina; Key West, Florida; Mare Island, California; and Pearl Harbor.
2. Guided missile ships: Operating and maintaining guided missile simulation equipment.
3. Radar bomb scoring unit: Evaluation of tactical bombing operations. They are located at Jacksonville, Florida; Naples, Italy; Seattle, Washington; and Japan.
4. Naval Training Device Center, regional and area Offices: Assisting in the procurement, installation, evaluation, and maintenance of training devices. Regional and area offices are located at activities within the area assigned to the particular office. The TD conducts acceptance tests and evaluations of training devices.
5. Naval air stations and squadrons: Operating and maintaining instrument trainers, operational flight trainers, weapon system trainers, radar trainers, and loran trainers. In general, the majority of senior TD's are assigned to these types of billets.
6. Naval stations: Operating and maintaining trainers for shipboard operational equipments such as radar target generator, gun turret, and missile trainers.

There are a number of special programs and projects to which TD's may be assigned. Some of these involve research; others may involve testing or evaluation. An example of such an assignment is the Air Crew Equipment Laboratory, Philadelphia, Pennsylvania. Its mission is to test and evaluate new flight clothing for high speed and space flight.

For a listing of other programs and projects, reference should be made to the Enlisted Transfer Manual and BuPers Instruction 1306.14H (TD Data Card).

Instructor duty is available to both the TD1 and TDC in the following schools:

1. Aviation Familiarization School (Class P).
2. Aviation Electronics Fundamentals School (Class A).
3. Tradevman School (Class A).
4. Tradevman School (Class B).

In addition to the above listed instructor billets, the assignment may be to instructor duty with a Naval Air Maintenance Training Unit (NAMTU). NAMTU's are located at shore stations on both coasts. Personnel assigned to this duty are first sent to Naval Air Maintenance Training Group headquarters at Memphis, Tennessee, for a period of indoctrination and instruction.

It is also possible that the TDC may be assigned to the Navy Training Publications Center, Memphis, as a technical writer in the preparation of training course materials. This training course is an example of such materials.

Another possibility is assignment to the Examining Center, Great Lakes as an item writer for the examination materials for the Tradevman rating.

Instructor billets are normally filled on a voluntary basis. Detailed information concerning assignment to instructor duty is contained in the Enlisted Transfer Manual, NavPers 15909-A.

Personnel may indicate their desire for assignment to a specific program or project by indicating it in the "remarks" block of their TD Data Card, NavPers 2926 (10-62).

You have now worked within the Tradevman's rating long enough to realize the importance of the rating to naval aviation and shipboard training. The personnel who man naval aircraft and ships depend upon you for much of their training. The operational commanders rely upon you to help keep their personnel in the highest state of readiness for the successful accomplishment of their assigned missions. You must realize that the utmost care and efficient workmanship are demanded of men of your rating.

With newly developed weapons and associated equipment, the work of the TD is more important than even before. Advanced methods of tactical operations; the increased use of detection equipment, special weapons, and guided missiles; more efficient training methods; and more sophisticated support equipment demand their share of attention. New types of computers, launching and handling equipment, surface craft, aircraft, and testing equipment are rapidly becoming part of the daily stock-in-trade of the TD. It is imperative that he keep abreast of these fast-breaking technological developments to remain a leader in the Tradevman rating.

Among the duties of all Tradevman is to contribute to the maximum availability and utilization of training devices by proper maintenance supervision of the electrical, electronic, and mechanical equipment used in a trainer.

Thus as the leading TD you are going to be vitally concerned with carrying out the activities' mission, and the Navy's mission, through people—which is naval leadership.

As a result of the naval leadership program a considerable amount of material related to naval leadership for the senior petty officer is available to you. Studying this material will make you aware of your many leadership responsibilities as a senior petty officer and will also be of great help to you in developing your leadership qualities. However, it will not, in itself, make you a good leader. Leadership principles can be taught, but a good leader acquires that quality only through hard work and practice.

As you study this material containing leadership traits, keep in mind that probably none of our most successful leaders possessed all of these traits to a maximum degree, but a weakness in some traits was more than compensated for by strength in others. Critical self-evaluation will enable you to realize the traits in which you are strong, and to capitalize on them. At the same time you must constantly strive to improve on the traits in which you are weak.

Your success as a leader will be decided, for the most part, by your achievements in inspiring others to learn and perform. This is best accomplished by personal example.

ADVANCEMENT IN RATING

By this time, you are probably well aware of the personal advantages of advancement in rating—higher pay, greater prestige, more interesting and challenging work, and the satisfaction of getting ahead in your chosen career. By this time, also, you have probably discovered that one of the most enduring rewards of advancement is the training you acquire in the process of preparing for advancement.

The Navy also profits by your advancement. Highly trained personnel are essential to the functioning of the Navy. By each advancement in rating, you increase your value to the Navy in two ways. First, you become more valuable as a technical specialist in your own rating. And second, you become more valuable as a person who can supervise, lead, and train others and thus make far-reaching contributions to the entire Navy.

Since you are studying for advancement to PO1 or CPO, you are probably already familiar with the requirements and procedures for advancing in rating. However, you may find it helpful to read the following sections. The Navy does not stand still. Things change all the time, and it is possible that some of the requirements have changed since the last time you were going up for advancement in rating. Furthermore, you will be responsible for training others for advancement, and so will need to know the requirements in some detail.

HOW TO QUALIFY FOR ADVANCEMENT

To qualify for advancement in rating, a person must:

1. Have a certain amount of time in grade.
2. Complete the required military and professional training courses.
3. Demonstrate the ability to perform all the PRACTICAL requirements for advancement by completing applicable portions of the Record of Practical Factors, NavPers 760.
4. Be recommended by his commanding officer.
5. Demonstrate his KNOWLEDGE by passing a written examination on (a) military requirements and (b) professional qualifications.

Some of these general requirements may be modified in certain ways. Figure 1-1 gives an overall view of the requirements for advancement of active duty personnel; figure 1-2 gives this information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your information and education officer to be sure that you know the most recent requirements.

When you are training lower rated personnel, it is a good idea to point out that advancement in rating is not automatic. Meeting all the requirements makes a person ELIGIBLE for advancement, but it does not guarantee his advancement. Such factors as the score made on the written examination, length of time in service, performance marks, and the quotas for the rating enter into the final determination of who will actually be advanced.

HOW TO PREPARE FOR ADVANCEMENT

Preparation for advancement in rating includes studying the qualifications, working on the practical factors, studying the required Navy Training Courses, and studying any other material that may be specified for the rate and rating. To prepare for advancement yourself or to help others prepare for advancement, you will need to be familiar with (1) the "Quals" Manual, (2) the Record of Practical Factors, NavPers 760, (3) a NavPers publication called Training Publications for Advancement in Rating, NavPers 10052 series, and (4) Navy Training Courses. The following sections describe these materials and give some information on how to use them to best advantage.

The "Quals" Manual

The Manual of Qualifications for Advancement in Rating, NavPers 18068 (with changes), gives the minimum requirements for advancement to each rate within each rating. This manual is usually called the "Quals" Manual, and the qualifications themselves are often called "quals." The qualifications are of two general types: (1) military requirements, and (2) professional or technical qualifications. Military requirements apply to all ratings rather than to any one rating alone. Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups. Then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS.

The professional qualifications for advancement in your rating used in the preparation of this course were current at the time this training course was printed. However, the "Quals" Manual is changed more frequently than Navy Training Courses are revised. By the time you are studying this training course, therefore, the "quals" for your rating may have been changed. Never trust any set of "quals" until you have checked the change number against an UP-TO-DATE copy of the "Quals" Manual.

In training others for advancement in rating, emphasize these three points about the "quals":

1. The "quals" are the MINIMUM requirements for advancement to each rate within the rating. Personnel who study MORE than the required minimum will have a great advantage when they take the written examinations for advancement.
2. Each "qual" has a designated rate level—chief, first class, second class, or third class. You are responsible for meeting all "quals" specified for the rate level to which you are seeking advancement AND all "quals" specified for lower rate levels.
3. The written examinations for advancement in rating will contain questions relating to the practical factors AND to the knowledge factors of BOTH the military requirements and the professional qualifications.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	† E7 to E8	‡ E8 to
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted. Must be permanent appointment.	24 mos as E-8 10 of 1 years total servic must b enliste
SCHOOL	Recruit Training.	▨	Class A for PR3, DT3, PT3. ǂ AME 3	▨	▨	Class B for AGCA, MUCA, MNCA.		
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST	▨	▨	Specified ratings must complete applicable performance tests before taking examinations.				▨	▨
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.				Service-wide, selection board, and physical.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)	▨	Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition)	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		
	TARS are advanced to fill vacancies and must be approved by CNARESTRA.							

* All advancements require commanding officer's recommendation.
† 2 years obligated service required.
‡ 3 years obligated service required.
ǂ Effective 1 Jan. 1963.

Figure 1-1.—Active duty advancement requirements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
	FOR THESE DRILLS PER YEAR								
TOTAL TIME IN GRADE	48	6 mos.	6 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	24	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.		
DRILLS ATTENDED IN GRADE †	48	18	18	45	54	72	108	144	72
	24	16	16	27	32	42	64	85	32
TOTAL TRAINING DUTY IN GRADE †	48	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	24	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days		
PERFORMANCE TESTS				Specified ratings must complete applicable performance tests before taking examination.					
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 760, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.							
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.						Standard EXAM, Selection Board, and Physical.	
AUTHORIZATION		District commandant or CNARESTRA					Bureau of Naval Personnel		

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for drills and training duty.

Figure 1-2.—Inactive duty advancement requirements.

Record of Practical Factors

A special form known as the RECORD OF PRACTICAL FACTORS, NavPers 760, is used to record the satisfactory performance of the practical factors. This form, which is available for all ratings, lists all the military and all the professional practical factors. Whenever a person demonstrates his ability to perform a practical factor, appropriate entries must be made in the DATE and INITIAL columns. As a PO1 or CPO, you will often be required to check the practical factor performance of lower rated personnel and to report the results to your supervising officer.

As changes are made periodically to the "Quals" Manual, new forms of NavPers 760 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the "Quals" Manual. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement. Keep this in mind when you are training and supervising other personnel. If a person demonstrates proficiency in some skill which is not listed in the "quals" but which is within the general scope of the rating, report this fact to the supervising officer so that an appropriate entry can be made in the Record of Practical Factors.

When you are transferred, the Record of Practical Factors should be forwarded with your service record to your next duty station. It is a good idea to check and be sure that this form is actually inserted in your service record before you are transferred. If the form is not in your record, you may be required to start all over again and requalify in practical factors that have already been checked off. You should also take some responsibility for helping lower rated personnel keep track of their practical factor records when they are transferred.

NavPers 10052

Training Publications for Advancement in Rating, NavPers 10052 (revised) is a very important publication for anyone preparing for advancement in rating. This publication lists required and recommended Navy Training Courses and other reference material to be used by personnel working for advancement in rating. NavPers 10052 is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number. When using this publication, be SURE you have the most recent edition.

The required and recommended references are listed by rate level in NavPers 10052. It is important to remember that you are responsible for all references at lower rate levels, as well as those listed for the rate to which you are seeking advancement.

Navy Training Courses that are marked with an asterisk (*) in NavPers 10052 are MANDATORY at the indicated rate levels. A mandatory training course may be completed by (1) passing the appropriate Enlisted Correspondence Course that is based on the mandatory training course; (2) passing locally prepared tests based on the information given in the mandatory training course; or (3) in some cases, successfully completing an appropriate Navy school.

When training personnel for advancement in rating, do not overlook the section of NavPers 10052 which lists the required and recommended references relating to the military requirements for advancement. Personnel of all ratings must complete the mandatory military requirements training course for the appropriate rate level before they can be eligible to advance in rating. Also, make sure that personnel working for advancement study the references which are listed as recommended but not mandatory in NavPers 10052. It is important to remember that ALL references listed in NavPers 10052 may be used as source material for the written examinations, at the appropriate rate levels.

Navy Training Courses

There are two general types of Navy Training Courses. RATING COURSES (such as this one) are prepared for most enlisted ratings. A rating training course gives information that is directly related to the professional qualifications of ONE rating. SUBJECT MATTER COURSES or BASIC COURSES give information that applies to more than one rating.

Navy Training Courses are revised from time to time to bring them up to date. The revision of a Navy Training Course is identified by a letter following the NavPers number. You can tell whether a Navy Training Course is the latest edition by checking the NavPers number (and the letter following the number) in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061.

Navy Training Courses are designed for the special purpose of helping naval personnel prepare for advancement in rating. By this time, you have probably developed your own way of studying these courses. Some of the personnel you train, however, may need guidance in the use of Navy Training Courses. Although there is no single "best" way to study a training course, the following suggestions have proved useful for many people.

1. Study the military requirements and the professional qualifications for your rating before you study the training course, and refer to the "quals" frequently as you study. Remember, you are studying the training course primarily to meet these "quals."

2. Before you begin to study any part of the training course intensively, get acquainted with the entire book. Read the preface and the table of contents. Check through the index. Thumb through the book without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

3. Look at the training course in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the book.

4. When you have a general idea of what is in the training course and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it may be a chapter, a section of a chapter, or a subsection. The amount of material you can cover at one time will vary. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

5. In studying each unit, write down questions as they occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

6. As you study, relate the information in the training course to the knowledge you already have. When you read about a process, a skill, or a situation, ask yourself some questions. Does this information tie in with past experience? Or is this something new and different? How does this information relate to the qualifications for advancement in rating?

7. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Without looking at the training course, write down the main ideas you have learned from studying this unit. Don't just quote the book. If you can't give these ideas in your own words, the chances are that you have not really mastered the information.

8. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Navy Training Courses or other appropriate texts. As mentioned before, completion of a mandatory Navy Training Course can be accomplished by passing an Enlisted Correspondence Course based on the training course. You will probably find it helful to take other correspondence courses, as well as those based on mandatory training courses. Taking a correspondence course helps you to master the information given in the training course, and also gives you an idea of how much you have learned.

INCREASED RESPONSIBILITIES

When you assumed the duties of a PO3, you began to accept a certain amount of responsibility for the work of others. With each advancement in rating, you accept an increasing responsibility in military matters and in matters relating to the professional work of your rating. When you advance to PO1 or CPO, you will find a noticeable increase in your responsibilities for leadership, supervision, training, working with others, and keeping up with new developments.

As your responsibilities increase, your ability to communicate clearly and effectively must also increase. The simplest and most direct means of communication is a common language. The basic requirement for effective communication is therefore a knowledge of your language. Use correct language in speaking and in writing. Remember that the basic purpose of all communication is understanding. To lead, supervise, and train others, you must be able to speak and write in such a way that others can understand exactly what you mean.

Leadership and Supervision

As a PO1 or CPO, you will be regarded as a leader and supervisor. Both officers and enlisted personnel will expect you to translate the general orders given by officers into detailed, practical, on-the-job language that can be understood and followed by relatively inexperienced personnel. In dealing with your juniors, it is up to you to see that they perform their jobs correctly. At the same time, you must be able to explain to officers any important problems or needs of enlisted personnel. In all military and professional matters, your responsibilities will extend both upward and downward.

Along with your increased responsibilities, you will also have increased authority. Officers and petty officers have POSITIONAL authority—that is, their authority over others lies in their positions. If your CO is relieved, for example, he no longer has the degree of authority over you that he had while he was your CO, although he still retains the military authority that all seniors have over subordinates. As a PO1, you will have some degree of positional authority; as a CPO you will have even more. When exercising your authority, remember that it is positional—it is the rate you have, rather than the person you are, that gives you this authority.

Training

As a PO1 or CPO, you will have regular and continuing responsibilities for training others. Even if you are lucky enough to have a group of subordinates who are all highly skilled and well trained, you will still find that training is necessary. For example, you will always be responsible for training lower rated personnel for advancement in rating. Also, some of your best workers may be transferred; and inexperienced or poorly trained personnel may be assigned to you. Or a particular job may call for skills that none of your personnel have. These and similar problems require that you be a training specialist—one who can conduct formal and informal training programs to qualify personnel for advancement in rating, and one who can train individuals and groups in the effective execution of assigned tasks.

In using this training course, study the information from two points of view. First, what do you yourself need to learn from it? And second, how would you go about teaching this information to others?

Training goes on all the time. Every time a person does a particular piece of work, some learning is taking place. As a supervisor and as a training expert, one of your biggest jobs is to see that your personnel learn the RIGHT things about each job so that they will not form bad work habits. An error that is repeated a few times is well on its way to becom habit. You will have to learn the differ tween oversupervising and not su enough. No one can do his best wo supervisor constantly supervising. On hand, you cannot turn an entire job o inexperienced person and expect him correctly without any help or supervi

In training lower rated personnel, e the importance of learning and using terminology. A command of the techn guage of your rating enables you to re convey information accurately and to ideas with others. A person who understand the precise meaning of te in connection with the work of his definitely at a disadvantage when he read official publications relating to l He is also at a great disadvantage when the examinations for advancement in r train others in the correct use of terms, you will need to be very carefu own use of words. Use correct termin insist that personnel you are supervi it too.

You will find the Record of Practi tors, NavPers 760, a useful guide in and carrying out training programs. F record, you can tell which practica have been checked off and which ones yet been done. Use this information t training program that will fit the nee personnel you are training.

On-the-job training is usually c through daily and weekly work assi When you are working on a tight sche will generally want to assign each pers part of the job that you know he can do the long run, however, you will gain assigning personnel to a variety of job each person can acquire broad experi giving people a chance to do carefully su work in areas in which they are relat experienced, you will increase the skills of each person and thus imp flexibility of your working group.

Working With Others

As you advance to PO1 or CPO, you that many of your plans and decision large number of people, some of whor even in your own rating. It becomes inc important, therefore, for you to under duties and the responsibilities of per other ratings. Every petty officer in the Navy is a technical specialist in his own field. Learn as much as you can about the work of other ratings, and plan your own work so that it will fit into the overall mission of the organization.

Keeping Up With New Developments

Practically everything in the Navy—policies, procedures, publications, equipment, systems—is subject to change and development. As a PO1 or CPO, you must keep yourself informed about changes and new developments that affect you or your work in any way.

Some changes will be called directly to your attention, but others you will have to look for. Try to develop a special kind of alertness for new information. When you hear about anything new in the Navy, find out whether there is any way in which it might affect the work of your rating. If so, find out more about it.

SOURCES OF INFORMATION

As a PO1 or CPO, you must have an extensive knowledge of the references to consult for accurate, authoritative, up-to-date information on all subjects related to the military and professional requirements for advancement in rating.

Publications mentioned in this chapter are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to revision, make sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made.

A list of training courses and publications that will be helpful as references and for additional study in preparing for advancement is included in the reading list at the beginning of this text. Additional training courses applicable to the TD rating are available through your information and education officer.

In addition to training courses and publications, training film furnishes a valuable source of supplementary information. A selected list of training films that may be useful appears in an appendix of this training course. Other films that may also be helpful are listed in the U.S. Navy Film Catalog, NavPers 10000 (revised).

ADVANCEMENT OPPORTUNITIES FOR PETTY OFFICERS

Making chief is not the end of the line as far as advancement is concerned. Proficiency pay, advancement to E-8 and E-9, and advancement to commissioned officer status are among the opportunities that are available to qualified petty officers. These special paths of advancement are open to personnel who have demonstrated outstanding professional ability, the highest order of leadership and military responsibility, and unquestionable moral integrity.

PROFICIENCY PAY

The Career Compensation Act of 1949, as amended, provides for the award of proficiency pay to designated enlisted personnel who possess special proficiency in a military skill. Proficiency pay is given in addition to regular pay and allowances and any special or incentive pay to which you are entitled. Certain enlisted personnel in pay grades E-4 through E-9 are eligible for proficiency pay. Proficiency pay is allocated by ratings, and NEC's, with most awards being given in the ratings and NEC's which are designated as critical. The eligibility requirements for proficiency pay are subject to change. In general, however, you must be recommended by your commanding officer, have a certain length of time on continuous active duty, and be career designated.

ADVANCEMENT TO E-8 AND E-9

Chief petty officers may qualify for the advanced grades E-8 and E-9 which are now provided in the enlisted pay structure. These advanced grades provide for substantial increases in pay, together with increased responsibilities and additional prestige. The requirements for advancement to E-8 and E-9 are subject to change, but in general include a certain length of time in grade, a certain length of time in the naval service, a recommendation by the commanding officer, and a sufficiently high mark on the Navy-wide examination. The final selection for E-8 and E-9 is made by a regularly convened selection board.

Examination Subjects

The examinations for pay grades E-8 and E-9 are divided into three sections: professional knowledge, supervisory knowledge, and common knowledge. The professional knowledge section is designed to measure, at an advanced level, a candidate's knowledge of his particular rating. The officers who prepare these questions are guided by the Manual of Qualifications for Advancement in Rating and the related bibliography in Training Publications for Advancement in Rating. Pertinent publications from among those listed in the military requirements section of NavPers 10052 are used as sources of the supervisory knowledge section. The common knowledge section contains questions designed to test the candidate's arithmetical, mechanical, and verbal reasoning capabilities. Questions for this section are drawn from basic mathematics, physics, and vocabulary development texts.

Sources of Information

In addition to the titles listed above, the following publications, distributed to Navy libraries and I and E offices, will assist the candidate for E-8 or E-9 in preparing for the examinations: College Entrance Examinations Study Material (limited distribution); High School Subjects Self Taught Book (Navy-wide distribution); Basic Mathematics (Navy-wide distribution); Mathematics Review (Navy-wide distribution); popular texts on psychology (Navy-wide distribution); various USAFI texts (Navy-wide distribution); and vocabulary development books (limited distribution).

ADVANCEMENT TO COMMISSIONED OFFICER

The Limited Duty Officer (Temporary) Program provides a path of advancement to commissioned officer status for outstanding petty officers of the Regular Navy. LDO's are limited, in their duty, to the broad technical fields associated with their former rating.

Advancement to LDO may be made from PO1 or above. Education, length of service, and maximum age limits are usually specified in the requirements for advancement to LDO. However, these requirements vary according to circumstances. If you are interested in advancing to LDO, ask your information and education officer for the latest requirements that apply to your particular case.

Another path of advancement to commissioned officer status is provided by the Integration Program. Enlisted personnel possessing the required qualifications may be appointed under this program to the grade of ensign in the Line, Supply, or Civil Engineer Corps of the Regular Navy. Education, length of service, and maximum age limits are included in the requirements for eligibility under this program. Eligibility requirements for this program, as well as for the other programs discussed here, are subject to change.

CHAPTER 2

ADMINISTRATION AND SUPPLY

Chief and first class petty officers must recognize the fact that they are an important part of the administrative organization. As leading petty officers, their duties entail not only the ability to instruct with, operate, and maintain highly specialized training devices, but they must also be able to perform many administrative duties. These include the preparation of correspondence and reports; using the proper supply procedures for the procurement, issue, accountability, and disposition of equipment, parts, and supplies; and supervision of enlisted personnel.

Their duties also include making recommendations to the training device officer relative to the improvement of procedures and practices as well as operational improvement, modification, and alteration of training devices and training aids. Each TD plays an important role in formulating operational procedures, improving maintenance techniques, and overall improvement of the division to better accomplish its assigned mission. He can do this properly only when he has a clear understanding of policies and procedures as well as his place within the organization.

OFFICE ADMINISTRATION AND SUPERVISION

CORRESPONDENCE PROCEDURES

The petty officer in charge of the training device office must be able to prepare and supervise the preparation of official correspondence. Since uniformity in the preparation of correspondence is necessary in the Department of the Navy, all official correspondence must be prepared in accordance with the basic instructions contained in chapter 16, U. S. Navy Regulations; BuPers Manual, NavPers 15791-A; Navy Correspondence Manual, SecNav Instruction 5216.5; SecNav Instruction 5211.3 series; and communications instructions and related publications issued by the Chief of Naval Operations.

Naval Letters

In preparing a naval letter, bond paper is used for the original, while plain manifold (tissue) paper is used for carbon copies. When letterhead paper is not available, the letterhead is typed or stamped in the center of the page, six lines or 1 inch from the top of the paper. The file number, serial number, etc., are blocked 2 inches from the right of the page.

"From" is typed seven lines below the last line of the address in the letterhead or four lines below, when prepared for mailing in a window type envelope. "From," "To," and "Via" are single spaced. "Subject," "Reference," "Enclosure," and the space between paragraphs are double spaced. The signature begins at the center of the page, four lines below the last line typed. "Copy to" is blocked at the left margin, two lines below the last line of the signature information. The left margin is 1 inch wide. Sample copies are shown in the Navy Correspondence Manual.

Official letters assigned a security classification (Top Secret, Secret, etc.) are required to have a serial number assigned for identification purposes. Routine correspondence need not be assigned a serial number unless a serial number is required by the officer in charge of the activity preparing the correspondence. Procedures for preparing and handling classified correspondence are contained in the Department of the Navy Security Manual for Classified Information, OpNav Instruction 5510.1B, and Automatic, Time-Phased Downgrading and Declassification System, OpNav Instruction 5500.40B.

Naval Speedletter

A naval speedletter is a form of correspondence intended primarily for use within the Department of the Navy. It is used for an urgent routine communication and is prepared on NavGen Form 1006. With approval of the appropriate official, the speedletter may also be used for correspondence with persons or agencies outside the Deparment of the Navy.

The primary purpose of the speedletter form is to call attention to the communication so that it is handled as promptly as possible by the recipient. When it is necessary to expedite the delivery of a speedletter, it may be sent by airmail or special delivery, or both. The speedletter blank is so designed that, if space permits, a reply may be made on the same blank if the originator has supplied an extra copy of the letter. When an extra copy has not been received, the reply may be made on the same form if an official record copy is not required. A sample speedletter is shown in the Navy Correspondence Manual.

Business Form Letters

The business form letter is used for correspondence addressed to persons or agencies outside the Department of the Navy. However, if the outside addressee is familiar with the naval letter, it may be used instead of the business form letter.

The first page of the business form letter is typed on letterhead paper. If printed letterhead paper is not available, the name and address of the activity are typed on plain bond paper. Continuation pages are typed on plain bond paper. Further instructions regarding stationery and copies are given in the Navy Correspondence Manual.

A business letter of less than one page in length is centered on the page so that it presents a well-balanced appearance. A short letter may be double spaced, and it may be typed with the left and right margins as wide as 2 inches. Full page and multiple page letters are typed with 1-inch margins.

Messages

The TD may be required to send a message when time does not permit the use of a naval letter or speedletter. For example, an immediate replacement may be required tioning training device to cont training program.

Messages are released by officer who is thoroughly fan existing instructions concernin preparation of messages. They and concise, and the number kept to a minimum. Maximum made of the United States ma service.

Endorsements

Endorsements are used to approve, or comment on the co which is forwarded through on dressees before reaching its fi When there is adequate space page, the first and subsequent are placed on the same page cont letter or prior endorsement. P is used for the original of an e manifold (tissue) paper is us copies.

When an endorsement is t preceding basic letter or a prec ment, a dash line is placed one last line in the preceding comn originator's code is placed one dash line. If endorsements are s page where no dash line is originator's code is typed six top of the paper.

The format of an endorse the same as that of a naval le the heading as illustrated in th spondence Manual.

Enclosures

Enclosures to naval letter further describe or identify item(s) for which the letter is wr

Enclosures to naval letters multiple address letters, speedle ments, or business form lette to associate them with the co which they are a part. Multiple same material may be conside enclosure and only the first labeled. The number of copi must, however, be indicated in notation in the letter. The la the lower margin of the first page of the enclosure, may be typed, stamped, or written.

Enclosures may be sent with the letter or under separate cover with a copy of the letter. Enclosures to be sent under separate cover without a copy of the forwarding letter attached are identified by the word "Enclosure" and the number, the abbreviated functional title of the addresser, the abbreviation "ltr," and the date of the letter as follows:

Enclosure (2) NAVTRADEVCEN
ltr 1 July 1964

Enclosures to be forwarded with the letter are numbered consecutively beginning with 1 as follows: Enclosure (1); Enclosure (2); etc.

When a multiple page document is forwarded as an enclosure, only the top page need be labeled. For detailed instructions on the preparation and forwarding of enclosures, consult the Navy Correspondence Manual.

FILING PROCEDURES

The Navy filing system is set forth in the Navy Directives System, SecNav Instruction P5215.1 series. This system is used by the entire Navy as the standard subject classification system for the filing of all correspondence, records, reports, and other documents.

It is the responsibility of the petty officer in charge of an office to set up an adequate filing system in accordance with that outlined in the Navy Directives System. The filing system is established in relation to the size and volume of correspondence processed by the particular office concerned. The larger the volume of material which must be filed, the more elaborate the filing system must be to handle the traffic. The main objective of any filing system is to facilitate the finding of any item in the files with the minimum amount of time and effort.

An index should be prepared and placed in the front of each file, listing the contents in the proper classification number order. The standard subject classification numbers (outlined in SecNav Instruction 5215.1 series) are used in the Navy for filing all correspondence and directives and consist of 13 major groups. Small activities may adapt these groups to their needs by preparing file folders for a minimum number of these major subject groups and arranging material within the folders according to classification number assigned. Larger activities may adapt the filing system to their needs by preparing folders not only for the major subject groups but also for the primary and secondary groups.

RECORDS AND REPORTS

In order to have a smooth-running division, it is important to develop an efficient system for keeping records and reports. Reports normally required by training device divisions are listed in table 2-1 and in the Training Device Guide, NavExos P-530-2. Certain other reports pertaining to device utilization and training of personnel are often required by the local command. A tickler file in which all reports are listed according to date required (weekly, monthly, or quarterly) is most helpful. Organizing this file, however, is only the first step in establishing a workable system. The petty officer who is responsible for training device reports must also develop a well-organized method for compiling the information required.

TD Data Card, NavPers 2926

Instructions for making this report are contained in BuPers Instruction 1306.14H. Since the contents of this report are used in determining duty assignments for Tradevmen, it is imperative that all information submitted be complete and accurate. Each man must fill out a personal TD Data Card as he checks into the division, listing such information as date on which he checked in, Navy enlisted classification code, schools completed, previous duty stations, devices on which he is qualified, marital status, dependents, date enlistment expires, and whether he is a maintenance man, an instructor, or both. He also lists choices for future assignments. These cards must be kept up to date if they are to serve their purpose well; hence the person must be sure to make a prompt entry of any changes that occur.

Training Device Report, OpNav 10171.1A

This report is made to show utilization and condition of major devices, operational flight trainers, and weapons systems trainers. Instructions for making the report are contained in OpNav Instruction 10171.2.

Since this report includes a listing of the hours each trainer is utilized and the type training given, it is important to keep accurate records and to make sure that information given in the report coincides with the same information listed in the trainer logbook.

Allotment Request, TDC 7303/1

Information for making an allotment request for installation, maintenance, and modification is contained in NavTraDevCen Instruction 7303.1 series, which can be found in the Training Device Guide, NavExos P-530-2. Although this request may be handled by the Comptroller's Office rather than by the training device office, all Tradevmen should be familiar with procedures involved in requesting and utilizing an allotment. Allotments are discussed later in this chapter in the section on supply procedures.

Field Services Report, TDC 4700/2

This report notifies the U.S. Naval Training Device Center of the work performed by contract service engineers and signifies that their work has been performed in a satisfactory manner and that proper use is being made of their services. If such is not the case, the officer signing the report adds an appropriate endorsement stating the facts.

The procedure for requesting the help of contract service engineers is described later in this chapter in the section on administrative assistance by the Center.

Report of Damaged or Improper Shipment, DD6

The purpose of this report is to improve shipping materials and methods. As shown in table 2-1, it is used for reporting any unsatisfactory packing and/or shipping procedures. It must be carefully filled out and photographs or sketches should be included whenever they will serve to clarify the report. Any suggestions for improving shipping procedures should also be included in the report.

If an urgently needed device is received in a damaged condition and is beyond local repair, two additional copies of the report are filled out and sent to the Training Device Center, along with a request for replacement of the device. The Center then takes steps for prompt replacement of the device, as well as overhaul of the damaged device.

Failure, Unsatisfactory or Removal Rep NavAer 3069

The FUR report is used when a fai occurs in an exchange item under the cogniza of the Bureau of Naval Weapons (BuWeps) purpose is to reflect reliability and performa of accountable BuWeps items. The FUR re takes the place of the Electronic Failure Rep DD 787, and also replaces the DOD Si Line Item Release/Receipt Document, DD F 1348-1, when BuWeps exchange items are tu in to supply. The large number of copie this report received at the Naval Techn Services Facility makes individual review practical, so all reports are processe punched card tabulating machine methods. this reason, completeness and accuracy in ing out the form are extremely import Instructions for filling out and submitting FUR report are contained in BuWeps Instr tion 13070.1.

Modification Information Report, TDC F 4720-2

Device modification is discussed in de in this chapter in the section on administra assistance furnished by the Center. NavTraI Cen Instruction 4720.1, contained in the Trai Device Guide, NavExos P-530-2, gives comp instructions for making out the modifica information report.

Modification Completion Report, TDC 47

This report is a post card which is fi out and sent to the Center as soon as a m fication is completed.

The Training Device Guide lists three a tional training device administration repo

Allotment Report, NavCompt Form 2
Allotment Report for Management by Ob Class, NavCompt Form 175.
Monthly Report of Civilian Employm NavExos 1126.

Since these reports are normally compl and submitted by the Comptroller's Office, TD is not usually concerned with them. Deta information about them can be obtained fron local Comptroller's Office.

NavExos, Department of Defense (DD), Training Device Center forms are reque on the DOD Single Line Item Requisition S tem Document, DD 1348. Instructions for fil

Table 2-1.—Training Device Reports.

Name of report	Instructions for making report	Form No.	Frequency	Date due
TD Data Card.	BuPers Instruction 1306.14H.	NavPers 2926 (new 10-62).	When reporting to new duty station, changes in qualifications, changes in personal status.	Not specified.
Training Device Report.	OpNav Instruction 10171.2.	OpNav Form 10171.1A.	Major devices, weapons systems, tactics, and crew trainers: Quarterly.	Must be received on or before the 15th day of Jan., April, July, and Oct.
Allotment Request.	NavTraDevCen Instruction 7303.1 series.	TDC 7303/1.	Quarterly.	Must be received by: 1 June for 1st quarter, 15 Sept. for 2nd quarter, 15 Dec. for 3rd quarter, 15 Mar. for 4th quarter.
Field Service Report.	NavExos P-530-2 and back of report form.	TDC 4700/2	Weekly, or at conclusion of engineer's services if such services were for a period of less than a consecutive week. A report is completed for each type of device serviced.	Not specified.
Report of Damaged or Improper Shipment.	BuSandA Manual, Vol. V, Chapter VII. Navy Shipping Document 1850-4. NavExos P-530-2.	Form DD 6	As required.	Report promptly when damaged shipment is received.

Table 2-1.—Training Device Reports—Continued.

	Data reported	Person(s) signing report
	Qualifications, date enlistment expires, primary duties of TD personnel, schools completed, next duty preferences, personal status and any additional information pertinent to future assignments to duty stations.	Training device officer and commanding officer.
	Device number, aircraft model simulated, serial number, utilization, hours since overhaul, and physical location.	Training device officer and authority superior to training device officer.
r	Total estimated obligations to be incurred from 1 July of current fiscal year to end of current quarter for each object class. Estimated requirements by object class during quarter covered by allotment request. Unobligated balance. (Subtract estimated cumulative obligations from funds granted.) Justification (details of operating requirements for which allotment is requested.)	Commanding officer or authorized delegate.
	Record of time expended, work performed, troubles encountered, corrective measures taken, information given to military personnel and recommendations or other pertinent information. Form is filled out for OFT's, weapon system trainers, and other devices.	Training device officer or other cognizant officer-in-charge.
- r	Used for reporting unsatisfactory preservation, packaging, packing, marking, loading, stowage, and handling of supplies, or reporting excessive preservation, packaging, packing, and dunnage in carloading. Deficiencies are described in detail and information to indicate possible causes of deficiency and recommended corrective action is included. Photographs should be included whenever possible.	Cognizant officer.

Table 2-1.—Training Device Reports—Continued.

Name of report	Instructions for making report	Form No.	Frequency	Date due
Failure, Unsatisfactory or Removal Report (FUR).	BuWeps Instruction 13070.1.	NavAer 3069 (Rev. 3-60).	As required.	As soon as possible after failure occurs.
Modification Information.	SpecDevCen Instruction 4720.1. (This instruction is in NavExos P-530-2.)	TDC 4720-2.	As required.	As required.
Modification Completion Report.	NavExos P-530-2.	TDC 4720/4.	As required.	Sent in promptly when modification is completed.

Table 2-1.—Training Device Reports—Continued.

Sent to	Data reported	Person(s) signing report
ALSO Information copy and photographs or sketches sent to BuSandA (Storage Division). ALSO One copy to Training Device Center.		
Original mailed to: Naval Technical Services Facility (MR) 700 Robbins Ave. Phila., Penn. 1st carbon: File copy Remainder of copies: Taken to supply when gear is turned in.	Used in place of EFR, DD 787, and the DD 1348-1, when failure occurs in BuWeps exchange items. Example: PPI indicators and synchronizers of APS 31 or APS 33 radar indicators. (It is not necessary to submit an EFR, DD 787, when a FUR report is submitted.)	Training device officer.
If modification alters military characteristics: TO Training Device Center VIA cognizant training agency. If modification does NOT alter military characteristics: TO Training Device Center VIA Command Channels.	Used to: Request authority to make a trial modification. Request training Device Center to develop a modification. Report completion of a trial modification.	Training device officer or person designated by him.
Training Device Center	Device designator, name, serial number, model number, modification name, date modification completed, and remarks.	Cognizant officer or petty officer.

out the DD 1348 are contained in the Training Device Guide, NavExos P-530-2. NavExos and DD forms are requested from the appropriate supply point as listed in NavSandA 2002, while Training Device Center forms are requested from the Center.

NavWeps forms are requested on Aeronautical Publications and Forms Order Blank, NavAer 140, which is to be submitted to the nearest BuWeps publications supply point as listed in NavSandA 2002.

SUPERVISION OF PERSONNEL

As a Tradevman First Class or Chief, you may be assigned to a billet in which you may be required to supervise instructors who teach in a classroom, shop, or on some type of synthetic training device. In such a billet, it is your responsibility to insure that the correct subject matter and skills are being taught. In addition, the presentation must be so effective that the trainees learn the required knowledge and skills well enough to perform the jobs for which they are responsible. Supervision must be constructive and, at the same time, eliminate mediocre teaching.

NavPers Form 16310-A, Guide for Observation of Instruction, is designed for use in supervision of actual instruction. This form is particularly adapted for group instruction in classrooms and in situations where the usual lesson plan organization is required and practical.

All supervisory personnel should reveiw the Manual for Navy Instructors, NavPers 16103-B, before beginning observations. The use of NavPers Form 16310-A, Guide for Observation of Instruction, is prescribed there, and the procedure is explained on the reverse side of the form. It is desirable to make written suggestions or comments on as many items as possible in preference to merely checking satisfactory, excellent, poor, or otherwise. Write in favorable comments on excellent items as well as suggestions on items which need improvement.

Training device learning situations involve additional factors not usually present in classroom instruction. Safety first and prevention of damage to expensive equipment and training devices are often items of paramount importance when the students are being taught in training devices. Most of this type of instruction centers around student practice. Actual instruction procedures in a trainer may vary from one student to another due to individual differences and different levels of experience. For this reason, instructor supervisors must not only be thoroughly familiar with the technical skills required but also the best methods to present information to the students.

A continuing program of training is necessary to make the TD's better at their jobs and eligible for advancement. Usually about an hour each day is a reasonable amount of time to set aside for training purposes. Of course, the training should not always be formal; it may be a group discussion on maintenance and operating problems. As a senior TD, you may be given the responsibility of establishing such a program.

An excellent program of training is to have each TD give a series of lessons on the equipment that he operates and maintains. He can point out the characteristics and special troubles that may be peculiar to certain of his equipments. He can also point out short cuts in servicing his equipment. One of the principal objectives is to have each TD know as much as possible about each training device at his activity. This type of program gives the entire division information and some working knowledge of each equipment.

Pay particular attention to the training of men who are weak in one or two phases of the work. If a man lacks skill in a certain type of work, give him a chance to practice it alongside a skilled worker.

Do not use hit-or-miss methods of teaching. Give the man a definite job to do and check him occasionally on the job. Give him all the help you can. Try to plan his training so that he can acquire the most knowledge and skill in the least amount of time.

When one of your better qualified personnel is working on an unusually difficult job, have some of the other men watch the operation. This procedure is invaluable from the standpoint of training, and it also serves as a well-deserved compliment to the man who is doing the work.

In addition to training on specific trainers or equipment, overall training in basic principles should be stressed. Through lecture and discussion and correspondence course study, the men may be taught the theory and principles of electronic equipment maintenance. Through demonstration they may be shown the right way to analyze the trouble in a piece of electronic equipment and to effect a repair. However, assuming that he has the proper background information, a TD learns best by doing. On-the-job training produces the real skill in the repair of equipment. Dexterity, precision, and the feeling for the tools used in repair work come only with experience.

As a senior Tradevman, you are responsible for seeing that the lower-rated petty officers and strikers in your unit receive the proper training to enable them to advance in rating. This requires knowledge, thought and planning.

SUPPLY PROCEDURES

It is important for every TD1 and TDC to be thoroughly familiar with the procedures used in procuring training devices, repair parts, and routine supplies required for use in their division since, as leading petty officers, they may be required to initiate supply action for items required for the division to perform its assigned mission.

MANAGEMENT RESPONSIBILITY FOR TRAINING DEVICES AND REPAIR PARTS

Inventory management of training devices is exercised by the U.S. Naval Training Device Center, while the Electronic Supply Office (ESO) is responsible for inventory management of training device repair parts. To distinguish training devices from repair parts, cognizance symbol O is assigned to complete devices (formerly T material). The inventory control plan for cognizance symbol O material is outlined in NavTraDevCen Instruction 4440.5. Cognizance symbol 8N is assigned to repair parts which are peculiar to training devices. The inventory control plan for cognizance symbol 8N material is outlined in ESO Instruction 4440.92B. A separate Navy Stock List is issued for cognizance symbol O and cognizance symbol 8N materials.

Many replacement parts for training devices are standard electrical and electronic parts assigned cognizance symbol N and are stocked in the electronic supply segment of the Navy Supply System. Training devices also contain some parts assigned cognizance symbol R (aviation parts), stocked in the aviation supply segment of the Navy Supply System, and cognizance symbol Z (ordnance parts), stocked in the ordnance supply segment of the Navy Supply System.

Since most cognizance symbol 8N repair parts are unpredictable in demand and many fall in the insurance type category, it is not considered feasible to stock these ite dispersed material distribution system. fore, two stocking points—NSC Oakla NSC Norfolk—have been established f nizance symbol 8N material. This cons inventories, reduces requisition pro time, and effects considerable econo stock financing and inventory manageme

Activities and ships having requi for training device repair parts should their requirements to the source of indicated below:

FOR FRACTION CODE	SOURCE OF S
H - - - - - - - - - - - - - -	ESO
M and S- - - - - - - - - -	Nearest dis bution p (NSC No NSC Oa

The necessity for economy in the repair parts requires the return to sto material which can be economically res ready-for-issue (RFI) condition. Thes are identified by fraction code H an source code of "repairable" in Training Maintenance Manuals. When a replacen a repairable cognizance symbol 8N need of repair is required, it is mandat the item in need of repair be retaine activity until disposition instructions a ceived from ESO. The requisition for r ment should indicate that a nonready-fo item is available for restoration.

APPROPRIATIONS AND ALLOTMENTS

An understanding of Navy approp and allotments is helpful for anyone deal supply procedures.

An appropriation is an authorizatio act of Congress to spend government fu specific purposes. Every Navy appropri assigned to one of the bureaus or office Navy Department for the purpose of adm tive control. They in turn make allotm the various activities under their mana or financial control to carry out their a mission.

Appropriations are identified by an ap ation number. For example, 1741804. the appropriation from which funds are r to maintain training devices in 1964. T two digits of a Navy appropriation denote the Navy Department, the third digit denotes the last number of the fiscal year (X denoting a continuing appropriation), and the fourth, fifth, sixth, and seventh numbers denote a particular appropriation. The remaining digits make up the appropriation subhead which further describes the appropriation.

The breakdown of the above appropriation is as follows:

17 4 1804 .1410

Navy Department	17
Fourth digit of fiscal year (1964)	4
Operation and maintenance, Navy	1804
Field services, ONR	.1410

Funds for Production of Devices

Each device is produced at the request of and with specific funds provided by the cognizant training agency, to meet known field requirements within budgetary limitations. For example, DCNO (Air) sponsors the funds for production of aviation training devices such as instrument trainers, operational flight trainers, and weapons systems; funds for the production of surface and subsurface tactics and weapon system trainers are provided for by the Deputy Chief of Naval Operations (Operations).

After the devices have been produced, the Training Device Center provides funds for installation, maintenance, and modification either directly, as when 8N cognizance material is drawn for repair parts; or indirectly, when an allotment is used to pay for such items as Navy Stock Account (NSA) materials or parts obtained through open purchase. (Allotments are discussed in detail in a later paragraph.)

NSA materials are of a standard nature and can be used for many different purposes. Thus they are not charged to a specific appropriation until actually issued for final use, at which time the bureau which draws the material is charged for it. ESO materials, prefixed by the cognizance symbol N, are also classified as NSA materials.

Materials which have already been paid for by an appropriation are classified as Appropriation Purchases Account (APA) materials. These are technical materials designed for a specific purpose, such as Aviation Supply Office (ASO), Ordnance Supply Office (OSO), and 8N cognizance items. Since these have already been paid for, they need not be charged to an allotment unless specific directives state that reimbursement is required.

Funds for General Overhead

Each naval station receives funds for general overhead from a quarterly allotment issued by the bureau exercising management or financial control over that station. For example, the Bureau of Naval Weapons issues a series Alfa allotment to naval air stations to finance routine maintenance and operation. This allotment is normally subdivided between the various station departments and covers such items as cleaning gear, office supplies, and materials needed for upkeep of buildings and grounds.

Allotments for Installation, Maintenance, and Modification of Training Devices

The Office of Naval Research (ONR) makes available, to the Training Device Center, funds for the installation, maintenance, and modification of training devices. This includes the fabrication and/or purchase of parts not procurable from Navy stock. This allotment also provides funds necessary to withdraw standard stock items from ESO, ASO, and OSO segments of the Navy Supply System, and Single Manager Operating Agencies, which require reimbursement in accordance with current directives. ONR authorizes the Training Device Center to issue direct allotments chargeable to this program. The Training Device Center, in turn, establishes procedures and administration, accounting, preparation, submission, and justification of suballotments requested under this program.

Regional and area representatives in charge of Naval Training Device Field Offices are authorized to supervise and direct the installation, maintenance, and modification of training devices. In the interest of economy and effective financial management, they also are authorized to review and evaluate fund requests from naval activities within their assigned geographic areas.

The commanding officer of the activity to which an allotment is issued is responsible for its proper administration. Accordingly, he insures that:

1. Allotments are administered in accordance with statutory and administrative requirements.
2. Funds are used in such a manner as to accomplish the programs, performance of work, or operations for which funds were appropriated and allotted.
3. All requests for funds are realistically priced.
4. Funds not necessary for current operations are returned to the allotting source so that savings can be realized, or more urgent requirements can be financed.
5. Persons responsible for a function or project are fully aware of the responsibilities attendant on the administration of appropriated funds.

The person designated by the commanding officer of each activity to administer the allotment is responsible for the use of allotted funds in accordance with current instructions and the requirements of the commanding officer. The duties include control over acts which reserve, obligate, and cause expenditure of available funds.

It is the responsibility of the activity furnishing fiscal support for the activity to which an allotment is made to maintain accounting records which can provide full disclosure of financial operations and resources and to prepare and submit all prescribed accounting reports required.

Requests for allotments for installation, maintenance, and modification are submitted on form TDC-7303/1 to the Center. (See table 2-1.) This form is filled out in accordance with the instructions contained on the reverse side.

REQUISITIONING TRAINING DEVICES AND REPAIR PARTS

Any activity of the Navy, Army, or Air Force may request training devices through the proper chain of command from the U.S. Naval Training Device Center. However, no blanket authorization exists for issuing training equipment to any activity, except for those items on a technical bureau allowance list. Devices are never furnished automatically.

When larger and more complex devices are produced, they are usually assigned directly to the field. Smaller devices, which have wide application, are normally available for issue to activities as requested and approved by the cognizant training agency; however, such stocks are held to a minimum for obvious reasons of economy.

Requests by Ship and Nonaviation Activities

Requests for training aids and devices are made to the nearest district training aids section, except that ships and stations in the Western Pacific Ocean areas may submit requests to one of the training aids libraries established in the areas. These libraries are located in Pearl Harbor, Hawaii, and Guam, Marianas. If these activities cannot comply with the request, they forward the request to the Bureau of Naval Personnel for processing. In the event the Bureau of Naval Personnel cannot fulfill the requirements of the request, the matter is referred to the Chief of Naval Operations for a decision.

Requests by Aviation Activities

Activities that procure training devices under the cognizance of DCNO (Air), including Marine aviation activities, submit requests for training devices and training aids through one of the following three channels:

1. If the device or aid is stocked by Fleet Airborne Electronics Training Units (FAETU's) or Aviation Training Aids Branches (ATAB's), the request is forwarded to the nearest of these units.
2. If the device or aid appears on the allowance list for Naval Air Reserve Training, the request is forwarded direct to the Training Device Center.
3. For all other devices and aids, a letter request is sent via DCNO (Air) to the Training Device Center. (An example of such a letter is shown in the Training Device Guide, NavExos P-530-2.) Station requisitions are never used for requesting training devices.

Requests by Marine Corps Activities

Activities under the cognizance of the Marine Corps (other than air activities) submit requests for training devices directly to the Commandant, Headquarters Marine Corps, Washington, D.C.

Requests by Activities Under Cognizance of BuMed

Activities under the cognizance of BuMed forward letter requests for training devices via the Chief, Bureau of Medicine and Surgery to the Training Device Center.

Requests by Army and Air Force Activities

Army and Air Force activities may obtain training devices from the Training Device Center by submitting a letter request via their appropriate Army or Air Force chain of command to the Center.

Letter requests for training devices should contain a paragraph appropriately worded as follows:

"Funds for this device are available under (cite the specific series of accounting digits used to indicate the appropriation, allotment, object classification, command responsible, etc. chargeable)."

The same information should also be given to cover shipping charges if shipping charges are chargeable to other sources. A paragraph should also be included to cover shipping instructions and any special instructions regarding distribution of information copies of shipping documents.

Summary of Requisitioning Procedures

The procedure for ordering training device repair parts is described in detail in TD 3 & 2, NavPers 10376-A. Some of the important points to remember are:

1. Repair parts are obtained through the use of form DD 1348 which must be signed by the head of the department or his authorized representative.
2. Items bearing fraction code H or source coded "repairable" in the maintenance manual are issued on an exchange basis only. DD 1348-1 must be properly filled out and presented at the supply office with the part to be turned in.
3. When Bureau of Naval Weapons items (not modified for training) are turned in to supply, the Failure, Unsatisfactory or Removal Report, NavAer 3069, is used in place of the DD 1348-1 form.
4. Complete records should be kept when ordering and receiving parts. This procedure expedites reordering and provides information on which parts have and which have not been delivered. In addition, it is important that the federal stock numbers indicated on issue documents be recorded when different from stock numbers listed on the applicable station requisition, DD Form 1348, and also when requisitioned repair parts were not previously identified with a federal stock number. This procedure assists trainer maintenance personnel in the preparation of future station requisitions for repair parts, expedites processing of requisitions by the local supporting supply department as positive identification of the material is given, and insures more timely receipt of items.
5. When unreasonable delay in the delivery of parts occurs, followup action should be initiated by preparing a DD 1348 (4-part) and contacting the supporting supply department for expediting action and status information. Followups using other methods may only cause further delay. In addition, the supply officer can be of assistance with any specific or general supply problems encountered.

INVENTORY AND ACCOUNTABILITY

The head of department is responsible for inventory and accountability of all equipage assigned to his department. Cognizance symbol O training devices and training aids are normally carried on the activity's plant account records if the unit cost of the item is $200.00 or more. Chapter 6, Volume 3 of the Navy Comptroller Manual outlines the criteria used in determining the items to be covered by plant property inventory and custody.

The head of department assists the fiscal office in establishment and maintenance of plant property records in the following procedures:

1. In obtaining technical descriptions and preparation and submission of property record cards.
2. In estimating costs where they are not otherwise available.
3. In affixing identification plates, etchings, decalcomanias, or inkings.
4. In determining the estimated life of plant property.
5. In conducting physical inventories.
6. In the expeditious closing of job orders or equivalent authorizations.

Tradevmen are normally required to assist in obtaining information for inclusion on the property record cards and in conducting inventories. Plant property is generally inventoried every 3 years. However, special inventories of specific activities or categories of plant property may be directed when such inventories are considered to be necessary.

A separate Property Record, DD Form 1342, is prepared for each individual equipment item of plant property. The individual property record form for accessories and auxiliary equipment, which is attached to or otherwise a part of an equipment item and which is required for its normal operation, is not maintained. However, the description of such accessory and auxiliary equipment is entered on the respective property record form.

The property record form for cognizance O material is prepared in accordance with procedures outlined in Volume 3 of the Navy Comptroller Manual. Special instructions for plant property reporting of cognizance symbol O training devices are outlined in NavTraDevCen Instruction 7321.2 and Training Device Guide, NavExos P-530-2.

When a piece of equipment is to be taken up in the plant account, it is assigned a Navy identification number. This identification number is affixed to the equipment by identification plate, steel die, inking, decalcomania, or some other suitable media so as to furnish future identification of the item.

The identification number assigned to cognizance O material consists of two elements: the accounting number of the activity or contractor's plant where the identification tag is affixed, and a 6-digit identification number suffix consisting solely of numbers. Numbers need not be assigned consecutively, but precautions should be taken to insure that the suffix number is not assigned to more than one piece of equipment. The fiscal officer assigns blocks of identification numbers to the various departments. He maintains records and strict control of all Navy identification numbers assigned by him. He maintains records of all Navy identification numbers in this series that are destroyed, mutilated, or for any other reason not used.

Inventory of plant property consists of the physical sighting of all items contained on the property record form. At the time of inventory, any items (of a plant account nature) found on hand and not already on the plant account records are taken up on the records. Action is also initiated at the time of inventory to expend from the records any items found to be worn out, broken, or unsuitable for use.

DISPOSAL OF TRAINING DEVICES AND REPAIR PARTS

Property Redistribution and Distribution Regulation No. 1 (PR and D Regulation No. 1), NavExos P-149, outlines the official procedure for the redistribution and disposal of Navy property, including training devices and repair parts. It should be clearly understood that this regulation does not curtail freedom to redistribute training devices within a command; it is intended to apply solely to those devices in excess of current needs.

When a cognizance symbol O training device becomes excess to the needs of an activity, the item is reported to the Training Device Center by letter (preferred) or on Standard Form 120, furnishing stock number, nomenclature, and material condition code (as outlined in NavExos P-530-2). The Center then provides the activity with disposition instructions. If the material condition so warrants, if the item is obsolete, or if the item is in excess of the needs of the Department of Defense, the Center directs the activity to expend the material from the records. Accountable material is expended on an approved survey and turned in to supply for salvage. Material having value as scrap is turned in to supply on DD Form 1348-1. Material having no value as scrap is disposed of by the activity.

Condition codes are assigned as follows:

CODE PREFIX	MEANING
N	New
E	Used—reconditioned
O	Used—usable without repairs
R	Used—repairs required
X	Of no further use as originally intended, but of possible value other than scrap.

CODE NUMBER	MEANING
1	Excellent
2	Good
3	Fair
4	Poor

For example, a condition code of N-1 means that the device is new and in excellent condition; while O-2 indicates that the device is used but is further usable without repairs and is in good condition.

Excess repair parts which are in all respects ready for reissue, repairable, or of value as scrap should be turned in to supply on DD Form 1348-1 for screening and disposition. Worn, broken, or damaged parts having no value as scrap or as an overhaul item are disposed of locally by the activity.

ADMINISTRATIVE ASSISTANCE BY NAVAL TRAINING DEVICE CENTER

The field services provided by the Training Device Center include the following:

1. Assistance in utilization of training aids and devices.
2. Field engineering assistance in installation, maintenance, and modification of training devices.
3. Assistance in the administration of Tradevmen.
4. Indoctrination of training officers and training device administrators (and certain enlisted men) in special courses held at the Center.
5. Furnishing of utilization and maintenance manuals and parts catalogs of devices, as well as other technical and training publications and reports of Center activities and developments.

UTILIZATION ASSISTANCE

The program of utilization assistance is designed particularly to provide assistance in the following four areas:

1. Fitting a device into the training program.
2. Gaining instructor acceptance of the device.
3. Training instructors to use the device most effectively.
4. Overcoming specific teaching limitations of a device. Any training activity may request assistance in the use of a training device by writing a letter to the Training Device Center.

In many cases, utilization assistance begins with a demonstration of the device by Center personnel to the training personnel of the receiving activity, immediately upon receipt of the device in the field. Since personnel limitations do not permit such an introduction of every device, nor is it always necessary, priorities for this service are determined on the basis of the following factors:

1. Importance of the device to the training program.
2. Critical nature of the training program.
3. Known problems in using the device.
4. Complexity of the training situation.
5. Cost and complexity of the device.
6. Requests from the training activity for a field demonstration.

In many cases, after a device has been in use for a while, Center personnel again visit the field, to further clarify the place of the device in the training program. They resolve any problems that may have arisen since the demonstration or introductory visit. The information gained at the second visit to the field is passed on to other users of the device.

FIELD ENGINEERING ASSISTANCE

Field engineering services offered by the Training Device Center include device installation, maintenance, modification, repair, and overhaul. These services may be performed by Center personnel, by personnel of Regional and/or Area Offices, or by contract engineers.

Requests for special assistance in installation, maintenance, or modification of a device are sent to the cognizant Regional or Area Office. Services provided by contractors are at no cost to the requesting activity. Requests should state the number and type of devices to be serviced, location of the devices, nature of the problem, date that the services are desired, and whether the work is urgent or routine.

In accepting the services of contractors, the activity should make arrangements to obtain the maximum value from the contractor's representative. The activity should provide all possible assistance and facilities as required to aid the representative in the performance of his duties. The officer in charge of the trainer installation signs the engineer's Field Service Report (TDC 4700/2). This report contains a record of the time expended, description of work performed, troubles encountered, corrective measures taken, information given to military personnel, and any recommendations or other pertinent information. If the work was not completed, the report should contain a statement explaining why as well as when it is expected to be completed.

Some field service engineers are also available to conduct specialized training courses in the operation and routine maintenance of certain complex devices at local activities. Requests for specialized training are sent directly to the Center. When instruction for a period longer than 2 weeks is to be conducted by the contractor's representative, the Center should be notified 60 days in advance of the desired date of the course. The number of local personnel to be trained, and the number of personnel from other activities that can be accommodated, should be stated in the request.

MODIFICATION OF DEVICES

Devices may require modification for one or more of the following purposes:

1. To improve circuitry or design.
2. To improve ease of operation.
3. To improve simulation of operational equipment.
4. To improve maintenance features.
5. To improve safety of operation.
6. To modernize training devices to conform to changes in operational equipment.
7. To adapt devices to new training requirements.
8. To tie in with other training devices or operational equipment.

Modifications are normally the result of recommendations proposed by the manufacturer, Center personnel, contract engineers, field personnel, and service test reports. Changes in operational equipment may require modification of devices so that device configuration gives the correct simulation.

Requests for modification of a training device are submitted on Form TDC 4720-2. These requests are prepared in accordance with NavTraDevCen Instruction 4720.1, a copy of which is contained in the training Device Guide, NavExos P-530-2. Modification assistance may be requested from the Training Device Center or from a Regional Office. After review of a modification request, the Training Device Center, by letter of acknowledgment, approves, disapproves, or states further action required before approval is given.

A modification order is issued by the Training Device Center to be accomplished by all activities having the particular training device. As soon as the modification is completed, this fact is reported by submitting the Modification Completion Report, TDC 4720/4.

OVERHAUL PROCEDURES

Facilities for the overhaul and repair of cognizance symbol O training devices are maintained at locations convenient to naval training activities. Any training device or component of a device may be reconditioned in the Training Device Shop of BuWeps Overhaul and Repair Departments at the following naval air stations:

NAS, Quonset Point, R.I.
NAS, Norfolk, Va.
NAS, Pensacola, Fla.
NAS, San Diego, Calif.
NAS, Alameda, Calif.

Basically, the work schedule of the Training Device Shops includes:

1. Planned programs.
2. Rehabilitation of condition code B training devices (non-RFI material).

Planned programs consist of work which can be planned or scheduled in advance, including periodic processing based on elapsed time or hours of use, and the processing of equipment which proves unreliable for unpredictable causes. Rehabilitation of B material concerns the reconditioning of devices when the demands of the training program warrant replenishment for system stock or immediate use.

To provide an orderly movement of devices through the Training Device Shops, shop schedules are issued quarterly, 90 days in advance of the period in which the work is to be done. Thus activities should remember, when submitting their requirements to the Training Device Center, that advance notification of 90 days is required for the preparation of schedules.

Overhaul and Replacement of Instrument Flight and Weapons Systems Trainers

If a device is "down" consistently, so as to seriously affect a training program, it should be so reported to the Training Device Center. When a trainer is in need of overhaul, the holding activity should notify the Training Device Center by letter and should indicate whether or not a replacement is required. The center then issues a shipment order authorizing trainer movement to a designated overhaul and repair point.

Overhaul and Replacement of Devices Other Than Instrument Flight Trainers.

To request overhaul and replacement of devices other than instrument flight and weapons systems trainers, activities should forward a letter request to the Training Device Center as noted above.

Shipping Procedures

All devices requiring repair, overhaul, or reconditioning are to be transferred to the overhaul point designated by the Training Device Center. The devices to be shipped are to be turned over to the supply officer for packing and crating. All packages and crates are to be marked "cognizance O material" for complete devices and "cognizance 8N material" for units of a device, including appropriate stock numbers, device numbers, and nomenclature.

INDOCTRINATION COURSES

The Training Device Center conducts a program of indoctrination and training courses for the training of active and inactive duty personnel. These courses are for the purpose of indoctrinating personnel in the procedures required to support the utilization of training devices in training programs. This includes the field services essential for proper installation and maintenance, and the assistance available from NavTraDevCen along with the procedures for obtaining this assistance.

Once each year, and prior to each course, all interested training commands and activities are informed by letter of the courses scheduled for the following fiscal year. The TD1 and TDC should attend as many of these courses as are made available to him. This broadens his knowledge relative to the latest equipments available, and the procedures used in procuring, maintaining, and disposing of them.

More detailed information about these courses can be found in the Training Device Guide, NavExos P-530-2. Requests to attend courses are sent to the Training Device Center via the chain of command.

CHAPTER 3

SUPERVISION OF MAINTENANCE

THE MAINTENANCE PROBLEM

The supervision of maintenance and repair of training devices is a major responsibility of senior Tradevmen. The complexity of the maintenance work is determined by the trainer and/or trainers involved. Training aids and demonstrators utilize simple mechanical and electromechanical units in their operation. These simple units can be kept in good working order with minimum personnel and effort, while complex trainers require highly qualified technicians and organized maintenance facilities.

The training devices at a particular station, ship, or training unit vary a great deal. Therefore, this chapter has been written in a general vein so as to include information that will be of value to the Tradevman supervisor no matter what his duty assignment.

PERTINENT MAINTENANCE PUBLICATIONS

In connection with maintenance and repair of training devices, a thorough knowledge of the use of various publications that are available to TD's will prove helpful. These include:

1. Handbook of Operation and Maintenance.
2. Training Device Logbooks.
3. Naval Training Device Center Field Service Bulletins.

Handbook of Operation and Maintenance

A handbook of this type is prepared for use as an aid in understanding and performing installation, maintenance, and adjustment procedures for each training device. It provides an excellent source of readily available material for each equipment. It is advisable for the Tradevman to spend some of his spare time in becoming familiar with its contents prior to his having to work on the trainer, rather than waiting until the need is at hand. This is especially true of the section on Theory of Operation and the section on Maintenance.

Training Device Logbooks

These records provide valuable information to the maintenance man by showing a continuous history of the performance and maintenance of a particular training device. When kept in accordance with instructions, the logbook serves as a valuable reference, aids in maintenance and repair work, and improves the quality and dependability of the training device.

Field Service Bulletins

These publications are issued periodically by the U.S. Naval Training Device Center (NTDC) to provide a medium for the exchange of information between field activities. Articles submitted by activities give worthwhile information on improvements in the use, modification, and maintenance of training devices.

MAINTENANCE AID

The NTDC has maintenance contracts with several commercial firms to assist in the maintenance and servicing of various complex training devices. Information on requesting assistance in maintenance and further information on the Center's maintenance aid program is contained in chapter 2 of this training course.

MAINTENANCE AND REPAIR FACILITIES

As a supervisor, a TD1 or TDC is expected to spot operating difficulties in his unit and correct them. He must understand his department, station or ship organization, and the proper channels and lines of authority which are open to him. The higher a petty officer progresses up the organizational chain, the greater are his administrative responsibilities.

The job of a supervisor is many sided and has a particular importance with respect to the operation of a maintenance and repair facility. A weakness in the performance of any supervisory duty or responsibility reduces the effectiveness of supervision.

The TDC should fully appreciate and understand the responsibility he holds as a member of the organization, and be able to identify each of his duties with respect to the whole--not an easy task in a field as complex and variable as the work of a supervisor. Therefore, only by study and analysis of each part of this job can he expect to prepare himself to execute these many duties effectively.

Some administrative personnel have made long lists of the responsibilities of supervisors. A close examination of such lists might disclose to each man the points of difference as well as the points of agreement. Many of the differences are of minor importance, but others represent real differences in responsibilities. The following list, although suggestive rather than arbitrary, includes the duties and responsibilities which are common to most TD supervisors:

1. Placing qualified personnel on the job at the right time.
2. Preventing conditions that might cause accidents.
3. Utilizing tools and materials as economically as possible.
4. Keeping personnel satisfied and happy on the job.
5. Adjusting grievances.
6. Maintaining discipline.
7. Keeping records and making reports.
8. Maintaining quality and quantity of repair work.
9. Planning and scheduling repair work.
10. Training personnel.
11. Requisitioning tools, equipment, and materials.
12. Inspecting and maintaining tools and equipment.
13. Giving orders and directions.
14. Cooperating with others.
15. Checking and inspecting repaired equipment and replacement parts.
16. Settling differences between personnel.
17. Promoting teamwork.

From the extent of the above list it is obvious that the job of a supervisor covers a broad field, and that a detailed study of such a job is not practicable in this limited space. These items are quite general in nature; therefore, it is necessary for each supervisor to carry out a detailed study of his own specific duties and responsibilities.

The TDC in charge should take advantage of every opportunity to provide the men with specific information about their jobs. If, for example, a man is making periodic inspections, his interest will be greatly stimulated by the chief telling him why the inspections are necessary and explaining the importance of his job with respect to the entire project. The type of chief who says, ''Never mind why; just do as you are told'' is rapidly being replaced by the supervisor who recognizes the importance of each man knowing why he is performing a job.

A chief should utilize all possible interest factors. He should study each of his men and use information gained to obtain the best results according to individual characteristics. His ability to interest his men in their work is important to him, as it has a part in determining his success or failure as a supervisor. His proficiency in rating depends in part on the quality and quantity of work his men produce, which in turn reflects the interest and morale of the men in their work.

SHOP LAYOUT

The physical dimensions of a repair shop vary throughout the Navy. The space requirements will vary with each activity. The result is generally that the available spaces must be used as efficiently as possible.

The leading petty officer should plan the layout of the shop in such a manner that the maximum number of repair jobs can be conducted at the same time.

An area should be provided for electronic repairs. This would include standard electronic benches which provide shelves for test equipment and electric power outlets for the equipment. Clearance around this work area should prevail to provide safety for the maintenance man. Rubber mats should be laid on the floor wherever electrical and electronic repairs are to be conducted. Lighting for this area, and the whole shop, should be carefully planned to provide maximum illumination.

A bench area should provide space for disassembling and overhauling small mechanical components. The layout of this bench should allow ease of cleaning of the disassembled equipment or components as well as the bench space. Bench equipment, such as a vise, grinder, or drill press, should be permanently mounted on the bench.

Floor space adjacent to the bench should be provided for the repair of equipments too large to be placed on the bench. Also, a doorway large enough for this equipment should adjoin the work area.

Space should also be provided for maintaining records, logbooks, etc. Clean and well-kept records and reports are good indications of well-planned supervision.

CARE OF TOOLS AND EQUIPMENT

Orderliness is a prime essential of good shop operation. There must be a place for every tool and each tool must be returned to its place after use. By seeing that this practice is observed, the men under your supervision will be able to find any tool at any time, without wasted effort.

In a shop, cleanliness, like orderliness, is a very important factor. If tools are to serve their purpose most satisfactorily, they should be wiped with a cloth containing light oil after they have been used. Tools in localities of high humidity should be wiped at least once a week (whether or not they have been used). In applying oil, care must be taken to see that it does not get on the wooden handles of saws, screwdrivers, and other tools.

An untidy shop is an unsafe shop. For this reason it is important that tools, machinery, workbenches, and floorspaces be kept clean. Piles of greasy and oily rags are fire hazards. Spilled oil on benches and decks may cause serious injury. All equipment should be checked to make sure that guards have been installed and retained on all moving parts of equipment.

Operating instructions and safety precautions should be posted at each machine. It is good engineering practice to comply with all the requirements listed in the operating instructions and safety precautions.

STOWAGE AND INVENTORY OF TOOLS AND EQUIPMENT

The number, character, and location of supply stowage spaces depend upon the particular room or building where the training device sh located. If the supplies for the shop are and heavy, the room should be accessib a delivery platform as well as easily acces to the shop which it serves.

The method of distributing tools and sup is also dependent upon the particular sh plan of distribution of supplies should be veloped as a part of shop planning.

Stowage racks and bins within a sto space are so dependent upon the materials handled that few general recommendations a It is necessary that maximum sizes and qu ties of materials be estimated in plannin size and location of the space. In orde facilitiate inventories and reordering, sup should be stowed in sight in open bins, r and shelves, wherever such arrangement be made, rather than in closed cabinets boxes.

SHOP HOUSEKEEPING

A quick survey for cleanliness, neat and stock stowage, and the condition of e ment will tell whether the workshop is organized and managed. A clean, well-orga shop normally reflects high quality mainten

Material and supplies must be stored convenient, secure, and orderly place. cabinets, shelves, bins, and racks arrang the shop to give the greatest possible a of free working space.

If shop space permits and sufficient are available, each rated man should hav own stowage drawer and toolbox in whic can keep the tools that are ordinarily This method of stowage not only provides b care and cleanliness of handtools but incre production.

If space permits, one corner of the shop be blocked off for use as a toolroom. A st should be made responsible for keeping tools in order and issuing them as requ This toolroom job should be rotated amon strikers to give each man an opportunity to l the names and uses of all the tools.

Tool stowage is an important item i shop. Lockers, racks, drawers, cabinets, boxes are used for stowing tools. The selected depends largely on the use of the the frequency of its use, its size and shape its value.

One of the jobs of the TDC in charge shop is to maintain a system of accounta for valuable tools and equipment. He should see that custody cards are made out for series 12000 (formerly title ''B'') tools and equipment. These include such items as portable power tools, gages, micrometers, and special sets of handtools. Tools which are of a high ''pilferable'' nature should be accounted for at regular intervals.

Tools and equipment used outside the shop should be made up in kits and stowed in convenient toolboxes. Tools used in the shop may be marked with a distinctive color for identification. If so marked, they are not easily mixed with tools that belong to other shops.

SAFETY PRECAUTIONS

The development of safety consciousness is an important part of every supervisor's responsibility. Safety in shops cannot be taught in a lesson or even in a series of lessons. Safety is actually a combination of attitudes and proper work habits which can best be developed by repeated emphasis of safety practices at all times and focusing attention on the prevention of accidents.

Safety instruction should emphasize both the physical elements (those inherent in a machine or in the operation of a machine) and the human elements (ignorance, carelessness, fatigue, etc.). Every operation should call attention to the safety factors involved. The supervisor should be alert at all times for evidences of carelessness and call them to the attention of the personnel immediately.

Accidents do not just happen--they are caused. Many accidents can be prevented by discovering and eliminating the causes. All analyses of operations that will be carried out in the shop should include analyses of safety factors. Investigating and analyzing accidents will help prevent their recurrence.

TRAINING MAINTENANCE PERSONNEL

If the TDC in charge of a shop has a well-planned program for introducing new personnel to the work in the shop, he has taken a most constructive step toward building shop morale. One of the best stimulants for the development of high morale among new personnel is to have them realize that the CPO appreciates their feeling of strangeness and is aware of their desire to make good. There is often a gap between the point at which a new man is assigned and the time at which he has developed into a satisfied worker. Proper introduction to the new work bridges this gap, turning an ill-at-ease person into a confident and interested worker. The chief is responsible for acquainting him with the working area and for developing him into a satisfied, well-balanced worker in his unit. During the early employment period, many of the things told to the new man ''go in one ear and out the other'' because his interest is centered on getting to the job, rather than on what he is told about the job.

The TDC will find it a profitable procedure to review with each man such matters as his duties, drills, liberty and leave regulations, and similar policies. This initial indoctrination need not take long, but the senior TD should be sincerely interested in becoming acquainted with the man and providing essential information about the department and work. The initial contact should be made primarily to win the man's confidence. The chief may later turn the man over to a qualified petty officer who is capable of completing the introduction process and the early training necessary. In most cases, considerable information can be given by an experienced petty officer selected by the chief.

In carrying out this responsibility the CPO must do a certain amount of planning if the instructions necessary for the proper indoctrination of the new worker are to be accomplished effectively.

At this point, it may be well to indicate one fundamental difference between the work of a supervisor and that of his men. The men work with machines and material, while the supervisor works through people to produce the desired results with the machines and material. The machines may be operating perfectly and the materials may be of the best quality, but unless the men who handle them are properly instructed, adjusted to their work, and cognizant of their place in the organization and of the policies of the department, they will not be satisfied workers.

The chief is responsible for developing high morale in his shop. The first step is attained by properly indoctrinating each man at the time he reports aboard. The three general areas of indoctrination are:

1. Those dealing with facts, such as the rules and regulations.
2. Those dealing with the man's attitudes or feelings, his confidence in the organization,

pride in the job, and respect for his fellow workers.

3. Those dealing with skills, safe working habits, and quality of work.

To aid in developing men for greater responsibilities is an all hands job. Each person not only must be receptive to that which helps to develop himself, but must also help to develop those who assist him. However, the CPO in charge has the direct responsibility to see that all subordinate petty officers understand their work and its relation to the function of the shop.

Additional information which will aid in the training of maintenance personnel is contained in Military Requirements Petty Officer 1 & C, NavPers 10057. NTDC field service engineers may be used to provide specialized on-the-job training for maintenance personnel. Arrangements for such assistance is normally made through the cognizant Regional or Area Office of the Naval Training Device Center.

MAINTENANCE AND REPAIR

The advanced Tradevman has already developed certain techniques in troubleshooting training devices. However, this portion of the chapter summarizes in a general way certain techniques or methods that may be applied to almost any type of electronic equipment.

The necessity for a thorough knowledge of the fundamentals of electricity, and electronics cannot be emphasized too strongly in performing any type of logical and systematic troubleshooting. The entire concept of effect-to-cause reasoning is based on a thorough knowledge of these fundamentals.

Because of the complexity of most naval electronic circuits, a malfunction can be the result of the complete failure of a small component or a small change of value of a critical characteristic of a component. The first situation requires the replacement of a part; the second situation may frequently be corrected by adjustments. It is this complexity that requires the development of a practical and logical approach whereby the possible simple causes are established or eliminated first. The difficult ones can then be pinpointed quickly. If necessary, replacements should be made prior to adjustments, otherwise the difficulty in isolating a faulty component may be greatly increased.

In all failures of electronic equipment, telltale evidence exists that will reveal the component (or major unit) in which the trouble exists. For this reason, the first step in troubleshooting should be localization. This localization process must be broken down into two phases--system localization and component localization. System localization involves localization of the trouble to a component, primarily by operational responses and in the case of operational trainers, by instrument indications. Component localization is finding the defective part within the system by any of the available means.

The sequence of steps to be followed in general troubleshooting will vary with the circumstances. The following is a list of suggestions to aid effective troubleshooting and is not intended to reflect a sequence:

1. Familiarization. Being familiar with the operation of the equipment and knowing the limits and capabilities of the necessary test equipment are prerequisites.
2. Symptom investigation. Checking the operator's impression of what happened at the time of failure, observing the operating condition of the equipment, and checking instrument indications are all important.
3. Visual inspection. This is a detailed inspection of components. The Tradevman looks for loose connections, burned parts, and other possible sources of trouble.
4. Odor. Burned parts may be detected by a distinctive odor.
5. Tube substitution. This means replacing suspected faulty tubes with known good ones.
6. Shock tests. Tapping suspected tubes with the finger or jarring the unit may disclose intermittent troubles.
7. Voltage tests. Normal voltage indications are listed in the equipment instruction book.
8. Resistance tests. Normal resistance indications are likewise included in the equipment instruction book.
9. Signal tracing. Waveforms are usually included in the equipment instruction book for comparison with test waveform results to determine the quality of the signal at various checkpoints.
10. Part substitution. This is the replacement of a suspected faulty part with a known good one. It may save time and effort in localizing trouble.

System troubleshooting, or localizing the trouble in a particular component, is a logical application of equipment familiarization and a practical utilization of symptom indications. In operational trainers, the task of locating the trouble may be simplified by operational checks, or instrument indications. These indications should give sufficient information to enable the TD to localize the trouble to one of the major components.

Unit, or component, troubleshooting is the localization of the trouble to a particular part. The block diagrams, schematic diagrams, troubleshooting charts, tube location diagrams, and other maintenance information are found in the equipment instruction book. These assist the TD in locating the faulty part. Obvious troubles, such as open filaments and fuses, loose connections, or arcing, can usually be determined by visual inspection and the presence of unusual odors.

Tube failures are common; therefore, tubes that are thought to be faulty should be tested and the bad ones replaced by tubes known to be good. Intermittent troubles may be caused by loose elements in tubes, and the shock test (tapping the tube) may be used to locate the trouble.

The making of voltage checks (when incorrect voltages are indicated) is often necessary, and is, in fact, standard procedure. When incorrect voltages are found, resistance checks may be made to establish the cause. If the trouble is caused by an open capacitor or other obscure cause that might not involve voltage changes, signal tracing may be employed.

If the TD is observant and employs analytical and logical effect-to-cause reasoning, oftentimes the component and even the individual part causing the trouble may be singled out before removing a single panel or inspecting a single computer.

PREVENTIVE MAINTENANCE

Most training devices comprise both complex electronic units and delicate mechanical equipment. Satisfactory operation, therefore, requires employment of the best standard maintenance procedures for both types of equipment in order to maintain the trainers in the best operating condition. It is necessary to adopt a systematic procedure for both daily and periodic inspection and servicing with the objective of anticipating and forestalling trouble, making immediate repairs, and in general assuring uninterrupted and smooth functioning of all units of the trainers.

Failure in the equipment during continued use may range from sudden breakdown, where the seat of the trouble is at once clear, to general overall wear and deterioration of the various components over a long period of time. Particularly, guard against general overall deterioration by conducting complete inspections and tests, both daily and at periodic intervals.

A log must be maintained to record all failures, alterations, and observations concerning the equipment, thus permitting a valuable systematic use of accumulated operational and maintenance experience.

Periodic Inspections

The main operating units of the trainer must be checked each day. It is desirable to make daily visual and operational inspections to anticipate functional difficulties. The Handbook of Operation and Maintenance gives detailed information on how the checks and inspections should be conducted.

The daily inspection should include both a visual and an operational check. The trainer should be checked visually for loose leads, improper connections, leaking capacitors, etc., prior to applying power to the equipment. The observations of the operational function of a trainer and the indications received will aid in establishing whether the trainer is functioning properly. An improper indication will aid in localizing the trouble to a component assembly or subassembly.

The daily inspection will often reveal discrepancies that may be corrected at that time with minimum amounts of labor and parts. Such discrepancies, if left uncorrected, might result in a major maintenance problem.

The complete system should be checked at regular intervals. Experience will determine how often these checks are necessary. However, it is better to check too often than to permit breakdown to occur. The Handbook of Operation and Maintenance Instructions will provide information on how periodic inspections should be carried out. To insure that the equipment is maintained in its best condition and at peak performance, the following general procedures should be followed:

1. Always keep equipment clean.

2. Measure the outputs of all power supplies at frequent intervals. Make any necessary adjustments.

3. Make visual checks of functioning of all mechanical units, such as motors, gears, differentials, bearings, etc., that are visible when equipment is in operation.

4. Become familiar with normal sounds of relays and rotating parts; characteristic appearance of tubes and dials; and temperatures of tubes, transformers, motors, and resistor assemblies while the equipment is in operation.

5. Always tighten all holddown screws on cable mounting lugs and terminal boards whenever maintenance is performed on the trainer. However, it is not advisable to tighten setscrews on gears, shaft couplings, and other rotating components as a routine procedure while performing other maintenance. Such tightening could introduce backlash, disturb critical adjustments, or strip the screw threads.

CORRECTIVE MAINTENANCE

In maintaining and servicing operational trainers, it is of primary importance to look for simple malfunctions. The method suggested below offers a good procedure for recognition and location of trouble:

1. Observation of controls and instruments.
   a. Do all controls have proper loading for the operational condition existing?
   b. Do all instruments register the appropriate indications?
   c. Do all instruments follow properly when operational conditions change?
2. Analysis for possible cause.
   a. If trouble exists, is it confined to a single system?
   b. Is it electrical or mechanical in nature?
   c. If electrical, can it be caused by
      (1) a faulty power supply?
      (2) a bad tube or tubes?
      (3) an open circuit?
      (4) a short circuit?
      (5) an open potentiometer?
   d. If the trouble is mechanical, can it be caused by
      (1) a loose cam?
      (2) a broken microswitch?
      (3) a jammed shaft?
      (4) fouled gear teeth?
3. Study of schematic drawings.

   a. Before using tools or test instruments, study the system and chassis schematics and analyze the problem as follows:

   (1) Break the trouble down into causes which could originate in a certain system or systems.

   (2) Localize the trouble to an area of the trainer.

   (3) Determine, if possible, which chassis is originating the trouble.
4. Preliminary testing.

   a. After the system or chassis causing the trouble has been tentatively determined, use the necessary tools and test instruments to determine which components are causing the trouble and adjust or replace them as required.

   b. It is rarely necessary to realine the entire trainer. It may be assumed that since the trainer was operating properly prior to the occurrence of the trouble, all potentiometers, cams, switches, etc., were then in proper alinement. Minor adjustments are normally made as required during regular inspection and maintenance periods. Therefore, an adjustment must never be undertaken until it first has been definitely ascertained that the adjustment is necessary. In many cases what appears to be misalinement will prove to be a defective tube, potentiometer, or some similar fault.

   c. In no case should any adjustment be attempted until the equipment has been turned on for sufficient time to assure that all components have arrived at a stable operating temperature condition. Adjustments made before the equipment has had time to warm up will ordinarily be faulty.

   d. Testing and alinement cannot be performed with inaccurate or inferior test equipment and instruments. The instruction handbook for the trainer will itemize the approved test equipment.

Not until the above checks are made should additional tests be undertaken. The troubleshooting charts in the maintenance handbooks give typical troubles and their causes, but for obvious reasons they are not intended as complete guides to troubleshooting.

By maintaining accurate maintenance logs it can be determined if troubles occurring in the trainer are caused from particular parts or circuits. A particular component may continually break down because of unusually high voltage, or methods used when operating the trainer. The records of continuing trouble will show a trend of future breakdowns. A study of the operation of the circuitry may indicate that a change in operating procedures is necessary, or a modification to the trainer should be made.

A trial modification can be made to the trainer provided that all of the following conditions are satisfied:

1. The trial modification is to be made on a single trainer.
2. The total estimated expenditure for materials and services does not exceed $100.00.
3. The proposed modification is of such a nature that the device can be returned to its original configuration.

In a case where all of these conditions cannot be met, or when an activity desires assistance to undertake the development of the modification, the procedure as set forth in NavTraDevCen Instruction 4720.1 (see the Training Device Guide, NavExos P-530) is to be followed.

SUPERVISING REPAIR WORK

One of the most important duties of a senior Tradevman is that of supervising repair work. He instructs personnel concerning the different repair jobs which must be done. He checks on the progress of the work, and gives additional advice or instructions when necessary. He should also check the job to see that it has been performed and completed properly and in accordance with his instructions.

After the CPO in charge has obtained complete information on a new job and has decided what repairs or replacements are necessary, he must then decide who is to do the job. In order to make this decision, the chief must know what experience the men have had with different types of repair work, and what skills they have in operating test equipment and in using tools.

When the workload is light and time is available, the chief can assign new jobs to relatively inexperienced personnel in order to give them training and experience. However, if a job must be performed in a short time, the chief will generally assign the job to one of the best men. In routine assignments, the more complicated and difficult repair work is given to the higher rated men and the less difficult jobs are given to the lower rated men. The assignment of a new job also depends a great deal upon the availability of tools, test equipment, and personnel.

STARTING THE JOB

The men who is going to do the repair job must be given detailed information on how the job is to be performed. The senior TD should be careful to see that the man fully understands what he is going to do, so as to prevent any mistakes due to misunderstanding of instructions. The amount of instruction depends upon the knowledge and experience of the man concerned. If he is an experienced rated man, it may only be necessary to tell him what repairs must be accomplished. Inexperienced men will need additional instructions on what test equipment to use, and the proper procedure to follow. Men should understand that they are free to ask any questions in case they are in doubt about any details in doing their assigned work. Men will ask questions when it is to their advantage to do so.

In addition to giving instructions on how a job should be accomplished, it is also advisable to give information concerning the importance of the job, the origin of the job, and the part that each person will play in accomplishing the complete repair job. In general, men are interested in why a job is necessary, and how it is to be accomplished, and will usually turn out better work when they have a clear picture of the total job.

CHECKING PROGRESS OF WORK

The assignment of work is only the first step in processing a job. The chief who is in charge must know his men. He should have a fairly good idea of each man's skill and ability, as well as his knowledge regarding the operation of equipment and accomplishing repair work.

The best way in which the TD supervisor can obtain this knowledge is to make frequent inspections and check the progress of work being performed. In that way, he will have a good idea as to which jobs, or which men, will require the most supervising.

When checking on the progress of work, the senior TD should be sure that the men are observing proper safety precautions in regard to themselves and the equipment they are operating. In addition, he should see that each man is using the proper tools, and note the quality of work being performed.

In case of any doubt, the chief should check to see that the men understand his instructions properly and are doing the work correctly. If necessary, the chief should provide additional instructions to give a better understanding of the job, or to improve workmanship. By frequently talking to the men and answering their questions, the chief can prevent work and material from being wasted, as could be the case if he were not available to give the correct details. The chief who has interest and confidence in his men and their work will find that men have confidence in him as a good supervisor.

Complications may develop on some repairs which may require additional planning and revised repair procedures. By observing the progress of the various jobs, and whether any are ahead or behind the planned schedule, the supervisor will be able to change the schedule in order to prevent "bottlenecks."

CHECKING ON COMPLETED JOBS

When a job has been completed, the senior TD in charge should inspect and approve the work. Inspection is necessary to insure that the repair job or the replacement parts will be satisfactory. Inspection of repaired equipment and replacement parts may be accomplished either visually or by means of measuring instruments. In addition, tests are performed to check the condition of repaired equipment.

The senior PO is responsible for determining whether the repair job, including replacement parts, meets the following standards:

1. Have the repaired parts been correctly installed in accordance with instructions?
2. Is the repaired item or replacement part free from defects in material and workmanship?
3. Have all parts or accessories to the repaired equipment been replaced or reinstalled correctly?
4. Has the proper replacement part been used in making repairs?
5. Has the part or item been properly checked and deemed ready for service?

The above are some of the things a chief must consider before the job is completed and the equipment ready to be used. No one should allow repair work to be considered complete until the chief, the TD repairman, and the operator of the equipment are satisfied.

INSTALLATION OF TRAINING DEVICES

In order to have the device available for utilization as soon after its arrival as possible and to insure optimum maintenance and performance, certain preparations should be made as soon as delivery of a device is anticipated. If assistance in planning is required, the cognizant Regional or Area Office of the Naval Training Device Center (NTDC) should be contacted.

Space and power requirements for the device should be ascertained in advance of delivery. The necessary arrangements for instal the device should be made. This may building modifications, additional e power and power equipment, and any ot tinent equipment or supplies. If power ments are unusual, or if the device or system is large, it may be necessary the assistance of the local public works ment. These requirements are usually the publications pertaining to the device may be obtained from the appropriate or area office.

Personnel requirements for installa maintenance of the device should be an prior to its arrival. If additional TD's quired, an increase in the station p allowance must be made.

If a new device is of such complexity NTDC considers factory training of Tr to be necessary, then the NTDC will aut ally make arrangements for this train personnel from the receiving activitie the course. The course is usually cond advance of shipping the device to allow details to be completed.

Specialized technical assistance necessary for the installation and initi tenance period of complex devices. NT mally provides this assitance under th of the contract with the manufacturer.

Any special tools, which may be requ device maintenance, are usually furnishe vice accessories. Requirements for repa should be anticipated and action taken as receipt of the new device is made kn

Early planning for the device's arri include the provisions for the fundin installation. Allotments are provided program and requests for funds are accordance with NTDC Instruction (through current change).

After the device arrives, the CPO i of the installation should see that adequa cautions are taken during the installati as to safety of personnel and care of the If a NTDC field service engineer or cont gineer is assigned, the CPO should see necessary manpower and facilities are av

Evaluation of the device is conduct all adjustments have been accomplishe predetermined operating time has elaps evaluation is accomplished with or wit assistance of NTDS. From this evaluatio can determine the feasibility of further p ments and possible modifications if nec

CHAPTER 4

ELECTRONIC TEST EQUIPMENT

A Tradevman must be able to test, adjust, and repair equipments containing electronic circuits such as power supplies, voltage and power amplifiers, phase detectors, amplitude modulators, and servomechanisms. He must be capable of testing these circuits for continuity, shorts, and grounds; and measuring electrical quantities such as voltage, current, power, frequency, and phase angles. This chapter discusses the application of electronic test equipment as well as some of the equipment circuits.

Many of the general-purpose electronic test instruments are described in detail in the Navy Training Courses Basic Electricity, NavPers 10086-A, Basic Electronics, NavPers 10087-A, and Tradevman 3 & 2, NavPers 10376-A. However, this chapter provides information on the selection of proper test instruments and their operating limitations.

USE OF METERS

Maintenance shops are equipped with various types of meters. They range in complexity from a simple plug-in ammeter to an electronic volt-ohm ammeter. The repairman must exercise judgment in the selection of the proper test instrument to insure the desired results. He must not only base his selection on the type of meter and its operating ranges, but must also consider the effect the meter will have on the circuit being tested.

AMMETER

The ammeter used for routine alinement and adjustment of a trainer is normally specified by the Maintenance Instructions Manual for the trainer. Since the ammeter has to be connected in series with the current path, circuits, requiring frequent current readings or adjustments normally provide current jacks for use with a plug-in meter. Some equipments have a meter installed as part of the equipment, with a meter switch to provide the necessary ranges.

OHMMETER

The Navy does not normally supply its maintenance facilities with an instrument consisting solely of an ohmmeter (an ohmmeter, AN/USM -21A is available for special applications). The ohmmeter is incorporated with the voltmeter to form a multimeter. Therefore, the choice of ohmmeter should be determined by the resistance ranges available in the various multimeters. Small multimeters, such as the TS -297/U, have a high range of R x 100; larger multimeters, such as the PSM-4, have a high range of R x 10,000. The VTVM TS-505A/U has a high range of R x 1,000,000 and should be used where high values of resistance must be measured.

D-C VOLTMETERS

The selection of a d-c voltmeter is normally based on the sensitivity of the meter movement and its effect on the circuit being tested. Meter sensitivity is discussed in Basic Electricity, NavPers 10086-A, Basic Electronics, NavPers 10087-A, and Tradevman 3 & 2, NavPers 10376-A.

A multimeter having low sensitivity may be used for quick, rough readings where approximations are adequate. When a high degree of accuracy is desired, a meter having high sensitivity is required. Such a meter has wide application in the maintenance of medium- and high-impedance electronic circuits.

A vacuum tube voltmeter, because of its high input impedance, is the ideal instrument for measuring low voltage in oscillators, automatic gain control, automatic frequency control, and other electronic circuits sensitive to loading. When measuring voltages in excess of 500 volts, a multimeter having a sensitivity of 20,000 ohms per volt will have an input impedance equal to or greater than most vacuum tube voltmeters. This can be proven by comparing input impedances of the two types of meters. The input impedance of most vacuum tube voltmeters is between 3 and 10 megohms. A 20,000-ohm-per-volt meter, when reading a voltage of 500 volts, would have an input impedance of 500 x 20,000 or 10 megohms. Therefore, on the 500-volt scale a multimeter of this sensitivity would have an input impedance at least equal to the vacuum tube voltmeter. For voltage readings over 500 volts, a 20,000-ohms-per-volt multimeter offers an input impedance higher than the vacuum tube voltmeter.

Any multirange voltmeter, though its sensitivity may not exceed 1,000 ohms per volt, can be used in an emergency to obtain reliable readings in a d-c circuit. If the impedance of the circuit being tested is not known, a comparison of two voltage readings—one on the lowest usable range and the other on the next higher range—will indicate if the meter is having a loading effect on the circuit. If the two readings are approximately the same, the meter is not causing appreciable voltage variations and the higher reading may be accepted as the true voltage. If the two readings differ considerably, the true voltage may be found by the use of the following formula:

$$E = \frac{E_2 - E_1}{\frac{E_1 R}{E_2} - 1} + E_2$$

where E is the true voltage
E_1 is the lower of the two voltage readings.
E_2 is the higher of the two voltage readings.
R is the ratio of the higher voltage range to the lower voltage range.

To illustrate the application of the correction formula, the following conditions are assumed:

1. A reading of 82 volts was obtained between two terminals with the meter on the 0-300 volt scale.
2. A reading of 22 volts was obtained between the same two terminals with the meter on the 0-30 volt scale.

The true voltage may be found as follows:

$$E = \frac{82-22}{\frac{22 \times 10}{82} - 1} + 82$$

$$E = 119 \text{ volts.}$$

A-C VOLTMETERS

The selection of an a-c voltmeter is more difficult in that frequency and waveform of the voltage being measured must be taken into consideration. Although some a-c voltmeters react to the peak value and others to the average (of one alternation) value, most a-c voltmeters are calibrated to indicate effective (rms) values of voltage. This is because effective values are generally more useful. (Rms is explained in Basic Electricity, NavPers 10086-A.)

Multimeters capable of measuring a-c voltages utilize conventional d-c meter movements and multipliers plus metallic oxide rectifiers to change the a.c. to d.c. Most multimeters have an accuracy of 2 to 5 percent at low frequencies. However, the shunt capacity of the metallic oxide rectifiers affects the accuracy of the multimeter as the frequency of the voltage being measured increases. When the frequency is above the audio range, the voltage reading is no longer usable. However, for rough readings the multimeter may be sufficiently accurate for most equipments. Where accuracy at the higher frequencies is desired, an a-c vacuum tube voltmeter should be used. Although many d-c vacuum tube voltmeters have an a-c voltage function, many circuits use the conventional metallic rectifier circuits mentioned above.

For measuring a-c voltages such as the trainer's power supply, the electrodynamometer or iron vane meter gives the most accurate measurement. Though the electrodynamometer and the iron vane meters are extremely accurate, their low input impedance makes their use prohibitive in most electronic circuits. Their use should be restricted to low-frequency applications and to circuits that are not affected by meter loading.

POWER SUPPLY

The Power Supply PP-106/U (fig. 4-1) is designed to supply various voltages for electronic

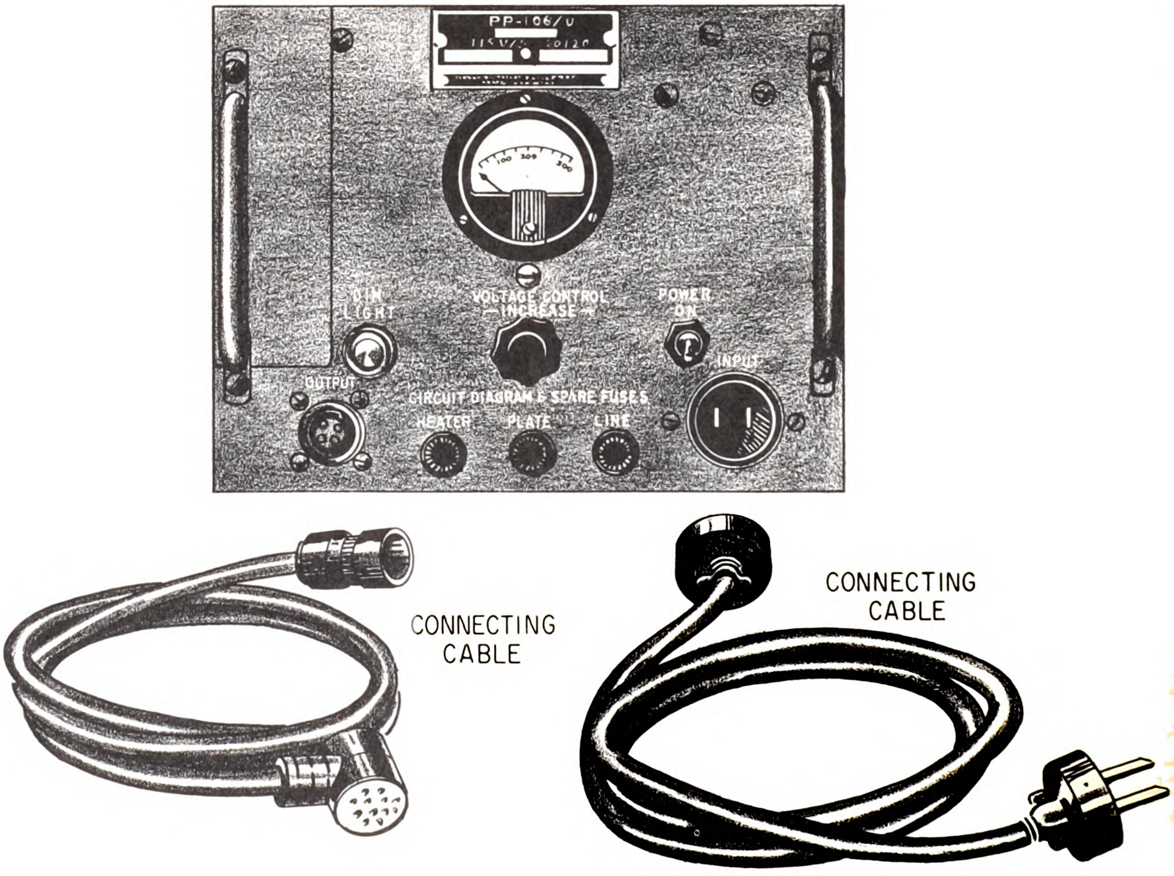


Figure 4-1.—Power supply PP-106/U.

equipments. Some test sets and frequency meters require voltages from an external source for their operation. Voltages and currents supplied are as follows:

1. 90 to 270 volts d.c. at 0.08 amp.
2. 270 to 300 volts d.c. at 0.06 amp.
3. 6.3 volts a.c. at 5 amp.
4. 12.6 volts a.c. at 2.5 amp.
5. 28 volts a.c. at 2.5 amp.

The PP-106/U contains a front panel meter and voltage control. The voltage control is used for setting the output d-c voltage. The a-c voltages are fixed and no adjustment is necessary.

Two connecting cables are required to operate the power supply. The input cable carries external power (115 a.c.; 60 cycles) to the power supply. The output cable is fitted with a seven-pin connector for connection to the electronic equipment requiring the voltages supplied by the power supply.

The a-c output voltages are obtained from a tapped secondary winding of a power transformer. The d-c output voltages are obtained from a full-wave rectifier using beam power amplifier tubes for voltage stabilization. Further stabilization is provided by the action of a VR tube.

Three fuses, mounted on the front panel of the power supply, protect the main circuits of the equipment. Spare fuses are mounted on the back (inside the cabinet) of the front panel.

SIGNAL GENERATORS

As indicated in Basic Electronics, NavPers 10087-A, a signal generator is a test equipment which generates an a-c signal which is suitable for test purposes. Most signal generators are constructed to generate a signal of any desired frequency. The signal may be modulated or unmodulated. If you have not recently reviewed the fundamentals of signal generators in Basic Electronics, you should do so before continuing with the present discussion.

AF SIGNAL GENERATOR

Tests and measurements made on many types of electronic equipment, such as amplifiers, modulators, and other voice-frequency apparatus, require a source of controlled audio-frequency oscillation usually with very little or no harmonic content. The frequency range required generally covers 20 to 20,000 cycles per second; however, some audio oscillators have ranges up to 200,000 cycles per second.

Several types of audio-oscillator stages are used to provide signals for the required amplitude and frequency. These circuits generally utilize resistance-capacitance (RC) oscillators and beat-frequency oscillators (BFO).

The RC oscillator provides audiofrequencies which are more easily controlled by varying the capacitance rather than the resistance. The change of frequency which can be produced by this method is limited; therefore, it is often necessary to cover the desired frequency range in several steps. This is accomplished by changing either, or both, the resistance and capacitance values.

A typical audio oscillator, often used for electronic maintenance, is the TS-382B/U. It should be remembered that the discussion to follow, although based on the use of a specific test equipment, is generally applicable to other signal generators of its type.

It should also be noted that AN/USM-30 is the overall nomenclature for the TS-382B/U, its transit case, and all its accessories.

The Audio Oscillator TS-382B/U (fig. 4-2) is a laboratory or shop device which generates a-c voltages ranging from 20 to 200,000 cycles per second at amplitudes which may be varied continuously from 0 to 10 volts. Its output frequency and amplitude are very accurate, making the instrument suitable for the measurement of gain and distortion in electronic circuits such as servoamplifiers.

Principles of Operation

The block diagram in figure 4-3 shows the following units:

1. The oscillator section which generates the audio voltage.
2. An amplifier which isolates the o from the external circuit and amplifies voltage.
3. An output level metering circ an attenuator.
4. A power supply.
5. An electronic voltage regulating
6. A frequency meter.
7. A cathode follower which isol meter from the remainder of the circu

The oscillator section (fig. 4-4) tubes V101 and V102. It is a Wier oscillator consisting basically of a tv resistance coupled amplifier which is to oscillate by the use of positive f (See Basic Electronics, NavPers 10087 detailed discussion of Wien bridge osci An RC network in the positive feedbac controls the frequency of oscillatio system. Any one of four ranges may be by means of the range switch S1. Ea four frequency ranges has a potentio calibration. The ganged capacitors, C connected to the main dial and provide of varying the frequency over the range by S1. The trimmer capacitors, C102 a are for tracking adjustments.

The output section consists of a tv resistance coupled amplifier, V103 a Negative feedback is used to minimiz tion and provide uniform output.

The output system consists of an level meter (M101), a gain control (R1 a six-section ladder type attenuator. Th meter operates from a full-wave type circuit in which germanium crystals a The gain control sets the voltage leve input of the ladder attenuator. The at is calibrated on the basis of the ins working into its rated load of 1,000 ohn

The voltage regulator (V106, V107, a supplies a constant output of 230 volts to circuits of the various tubes.

The voltage regulating system ope follows: Assume that the voltage acro R147, and R148 rises due to variatio voltage or changes in the load. The vo the control grid of V107 then increases. fore, the plate current increases, and creased current causes the plate vo decrease. Since the control grid of connected to the plate of V107, the vo this control grid also decreases. The through V106 then decreases, resto proper voltage across R146, R147, a

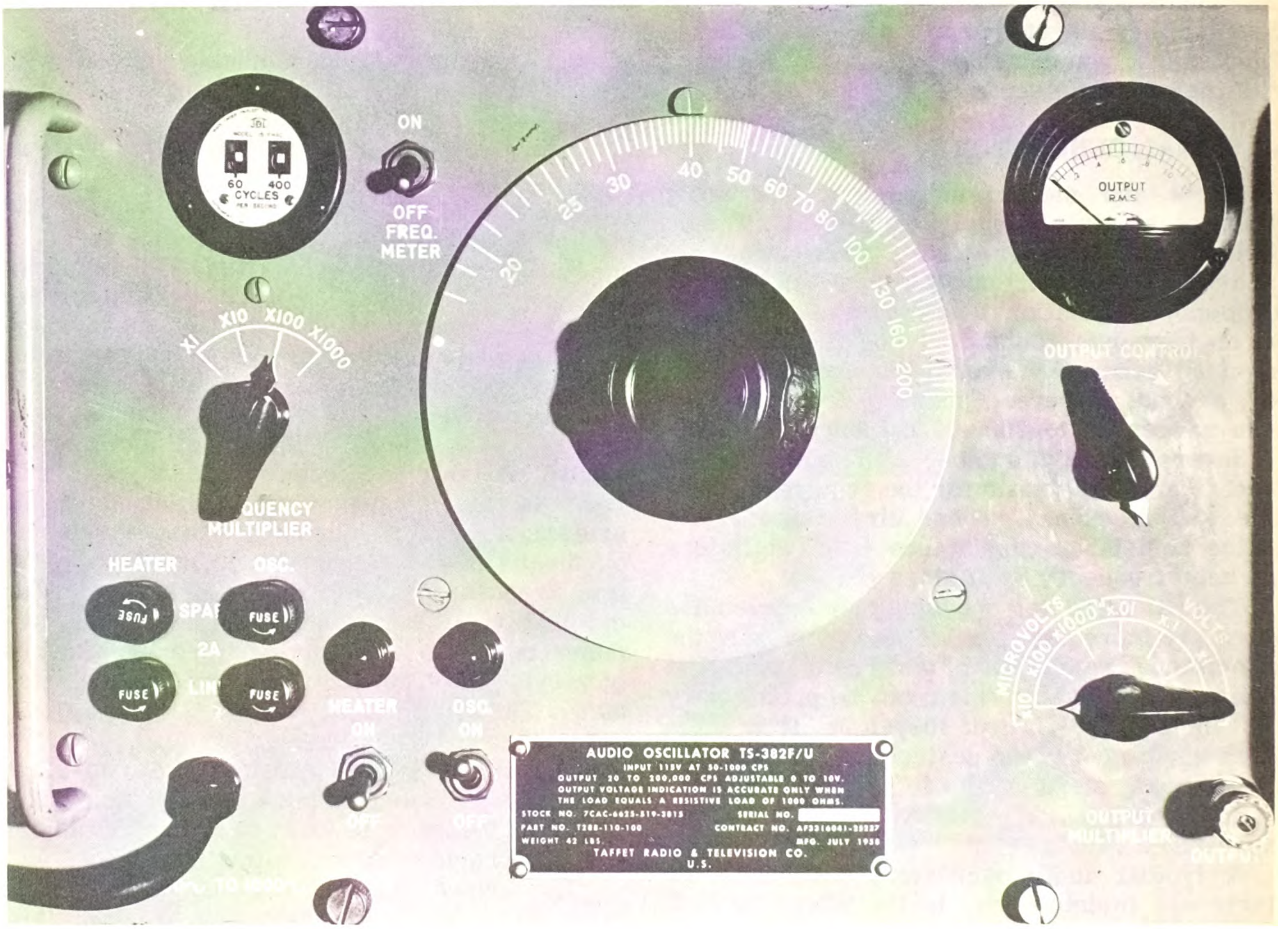

60 CYCLES 400
ON
OFF
FREQ. METER
X1 X10 X100 X1000
QUENCY MULTIPLIER
HEATER
OSC.
FUSE
HEATER ON
OSC. ON
OFF
OUTPUT R.M.S.
OUTPUT CONTROL
MICROVOLTS X10 X100 X1000 X.01 X.1 X1 VOLTS
OUTPUT MULTIPLIER
AUDIO OSCILLATOR TS-382F/U
INPUT 115V AT 50-1000 CPS
OUTPUT 20 TO 200,000 CPS ADJUSTABLE 0 TO 10V.
OUTPUT VOLTAGE INDICATION IS ACCURATE ONLY WHEN
THE LOAD EQUALS A RESISTIVE LOAD OF 1000 OHMS.
STOCK NO. 7CAC-6625-519-3815
SERIAL NO.
PART NO. T288-110-100
CONTRACT NO. AF33(604)-25237
WEIGHT 42 LBS.
MFG. JULY 1958
TAFFET RADIO & TELEVISION CO.
U.S.

Figure 4-2.—Audio Oscillator TS-382B/U.

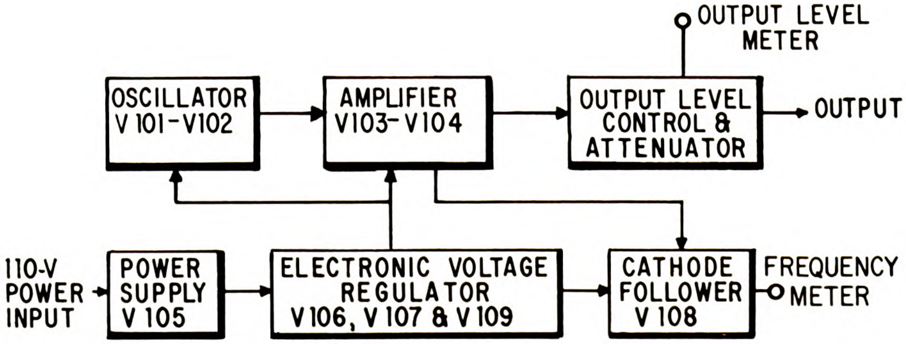


Figure 4-3.—TS-382B/U, block diagram.

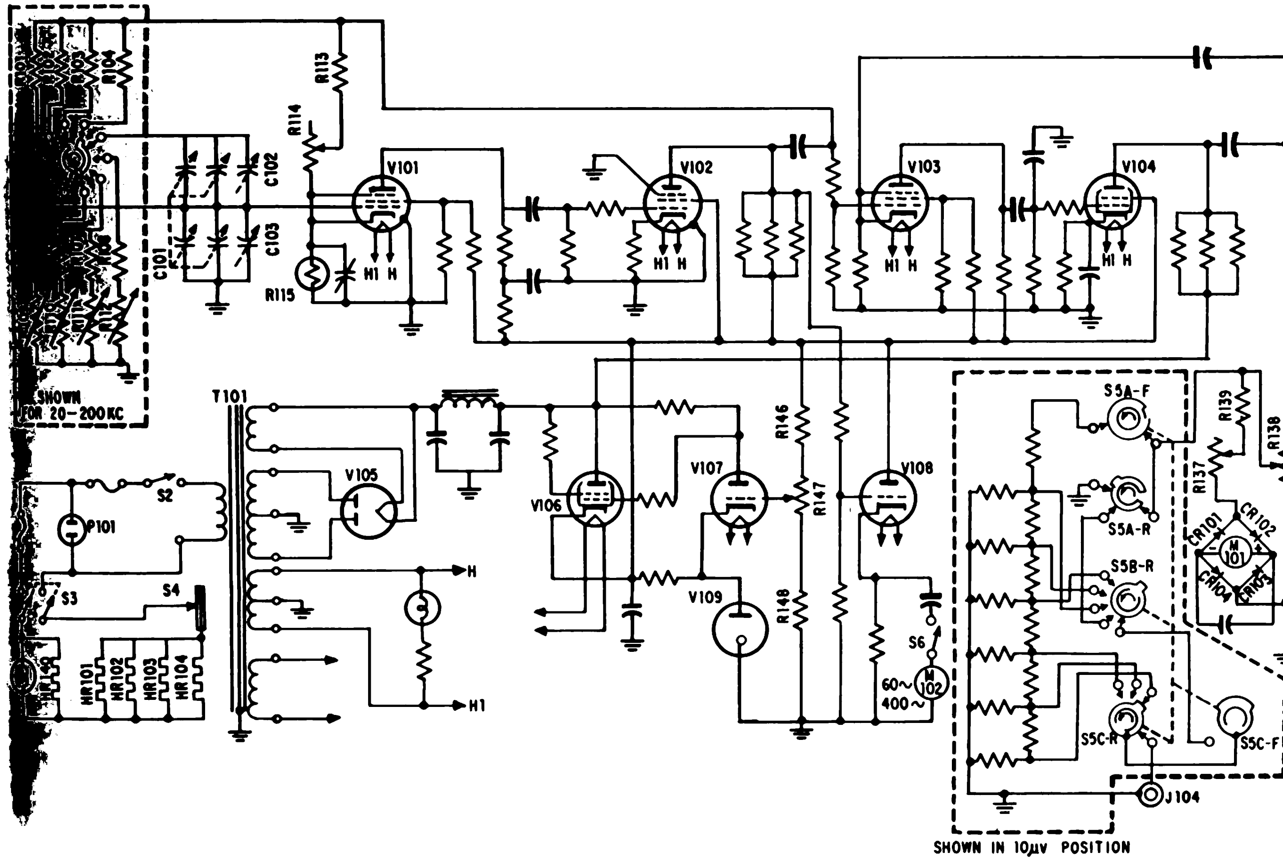


Figure 4-4.—TS-382B/U, simplified schematic diagram.

A vibrating reed type frequency meter (M102) permits an accurate check of the output frequency of the oscillator at 60-cycles per second and 400 cycles per second. The meter has been factory adjusted to an accuracy of three-tenths of one percent. This meter is isolated from the second oscillator tube (V102) by a cathode follower stage (V108) to prevent shifts in frequency when the frequency meter is in operation.

Five strip heaters are used to decrease the time required for the unit to reach stable operation and to permit satisfactory operation in colder climates. These strip heaters are regulated by a thermostat control switch on the front panel. An on-off switch and an indicator light are included in the circuit.

There are, at present, seven variations of the basic TS-382B/U. The latest model is known as the TS-382F/U. These are all basically the same with minor changes in circuitry, controls, cases, or accessories.

Details of operating procedure for the TS-382B/U may be found in the Operation Instruction Manual for the instrument.

Maintenance and Repairs.

Maintenance consists primarily of checkin for security of knobs and accessories. Car should be exercised to preclude the possibilit of the main tuning dial from becoming loos as this will affect the calibration of th instrument.

Proper operation of the audio oscillator ma be ascertained by checking its output at 6 cycles per second and at 400 cycles per secon against the built-in frequency meter. The mai dial is adjusted until the appropriate ree vibrates with maximum amplitude. The mai dial should read 60 cycles per second or 40 cycles per second within one or one and one half divisions, respectively.

Replacement of any tube other than those in the power supply involves recalibration of the instrument. Do not disturb any of the alinement adjustments as these will affect the frequency calibration.

Output Applications

The sine-wave of the signal generator is utilized in electronic maintenance. The TD will find sine-wave AF signals useful in checking gain and distortion in servoamplifiers and measuring output power.

SQUARE-WAVE OUTPUT.—Square waves have a wide use in the fast and accurate determination of the reproductive faithfulness of AF and video amplifiers. The use of square waves in checking amplifier frequency response reveals information about the phase characteristics of the amplifier which a sine-wave response check does not disclose.

To make an AF amplifier frequency-response check, connect the amplifier as shown in part (A) of figure 4-5. With the square-wave generator set to deliver the lowest frequency the amplifier is required to pass, throw switch S so that the generator output waveform appears on the screen of the oscilloscope. Adjust the oscilloscope controls to provide the best wave shape. Throw switch S to the amplifier output. The resulting pattern viewed on the oscilloscope may be distorted in several different ways, depending on which harmonic components of the input square wave are discriminated against either in amplitude or in time (phase). Part (B) of figure 4-5 shows several common response patterns encountered in checking amplifier response.

Next, increase the output frequency of the square-wave generator, and repeat the procedure listed above until the complete bandpass of the amplifier has been covered and the resulting patterns examined.

The frequency response of a video amplifier is checked in the same manner as an AF amplifier with the exception that only square-wave output frequencies of 30 cycles and 300 kc are used. If the response patterns show negligible distortion, the response of the video amplifier may be considered to extend as high as 15 times the fundamental frequency of the square wave.

RF SIGNAL GENERATORS

Radiofrequency signal generators comprise a rather large and very useful class of test equipments. Because of the extremely wide frequency range in the RF region of the spectrum, many signal generators with different RF ranges, as well as other instrument refinements, are available to the TD. The following general analysis of RF signal generators provides the principal circuits that are used in these generators.

In addition to the required power supply, the circuits common to most RF signal generators are the oscillator circuit, the modulator circuit, and the output circuit.

Oscillator Circuit

The oscillator has as its function the emission of a signal the frequency of which can be accurately set to any point in the designed frequency range. The type of oscillator used depends on the range of frequencies required. It may have as its resonant circuit a simple coil and capacitor (LC), a tuned line, a tuned cavity, or any of the various specialized types designed for microwave frequencies.

Modulator Circuit

The modulating circuit functions to change the RF output in accordance with the successive instantaneous voltage values of the audio or video modulating signal. For a particular generator the modulating signal may be provided by an internal source, by an external source, or by both, depending upon the design of the instrument. A meter is often included to indicate (and to permit control of) the percentage of modulation. The form the modulating signal may take depends upon the application of the particular signal generator. It may be a sine wave, a square wave, or a pulse.

Some instruments have special provisions for pulse modulation, which permits the RF signal to be pulsed over a wide range of pulse repetition frequencies (PRF) and at various pulse widths. An external synchronizing pulse may be used to initiate a generator pulse which, in some cases, may be delayed as long as 300 microseconds after initiation. In an AM signal generator, and audio oscillator is generally employed to modulate an RF oscillator. Frequency shift of the RF oscillator may occur

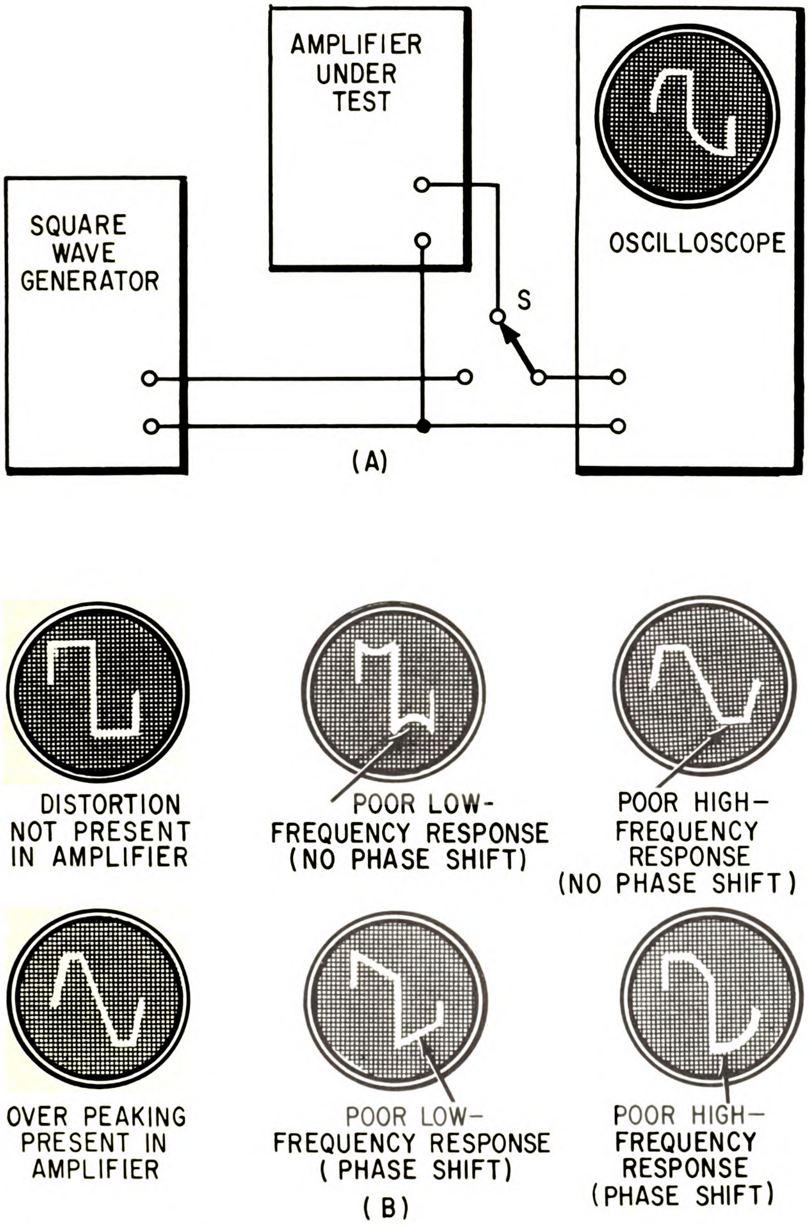

AMPLIFIER UNDER TEST
SQUARE WAVE GENERATOR
OSCILLOSCOPE
S
(A)
DISTORTION NOT PRESENT IN AMPLIFIER
POOR LOW-FREQUENCY RESPONSE (NO PHASE SHIFT)
POOR HIGH-FREQUENCY RESPONSE (NO PHASE SHIFT)
OVER PEAKING PRESENT IN AMPLIFIER
POOR LOW-FREQUENCY RESPONSE (PHASE SHIFT)
POOR HIGH-FREQUENCY RESPONSE (PHASE SHIFT)
(B)

Figure 4-5.—Checking an amplifier using a square wave.
(A) Test setup; (B) response patterns.

when an oscillator is directly modulated. For this reason the modulation percentage is generally kept at a low figure, usually about 30 percent. In FM or sweep generators, excessive frequency deviation (sweep) may produce a type of AM modulation of the RF signal. Although not always the case, this type of modulation may not be noticeable when the FM signal is fed to a receiver with limiter action. For this reason, and to avoid distortion in scope presentations, only sufficient deviation (sweep) should be provided to accomplish the purpose.

Output Circuit

The output circuit contains a calibrated attenuator and often an output-level meter. The output-level meter, which permits accurate control of the output of the oscillator, indicates arbitrary values of oscillator output. The attenuator selects the amount of this output that is required, and is usually calibrated in terms of microvolts. When the output-level meter is adjusted to unity (1), the attenuator provides a direct reading in microvolts. At other output-level meter readings, the decimal value of the reading is multiplied by the attenuator reading to give the microvolt output.

There are three general types of RF signal generators. They are the AM, the FM, and the PM (pulse-modulated) types.

FM SIGNAL GENERATORS

Various types of frequency-modulated signal generators are available; however, these generators are restricted to specialized applications with the exception of that type known as a sweep generator. The following general analysis of FM signal generators is given to provide the technician with basic information pertinent to all types of FM generators. Sweep generators are discussed separately following the general analysis.

An FM signal is one in which the output frequency varies above and below a center frequency. The overall frequency variation is known as the frequency swing (or deviation), and the rate at which this swing recurs is controllable at any audio (or video) frequency rate for which the generator has been designed. The frequency change of the output may be accomplished by the mechanical variation of either the capacitance or inductance of the oscillator circuit, or the use of a reactance tube connected to the oscillator circuit. In the latter case, changes of the voltage impressed on the grid of the reactance tube change the amount of reactance introduced into the oscillator tuned circuit, and as a result cause the output frequency to change. The frequency of the signal on the grid of the reactance tube thereby controls the rate of frequency deviation, and the amplitude of the signal voltage controls the amount of the deviation.

Sweep Generators

A sweep generator is a form of an FM signal generator the carrier deviation of which is adjustable by means of a sweep-width control; however, the sweep generator differs from the ordinary FM signal generator in that the rate of carrier deviation is generally maintained at a fixed frequency. The voltage used to effect the deviation may be either a sine wave (very common) or a sawtooth waveform. Since an oscilloscope is used to observe the patterns which are formed when the bandpass of interest is swept by this type of generator, the oscilloscope time base must utilize (or be synchronized with) the same waveform used to produce the deviation. The horizontal (or time) axis of the pattern then represents the instantaneous frequency of the generator output, while the vertical axis shows the response characteristic of the circuit under test for each frequency. Sweep generators are widely used for the observation of response characteristics and the visual alinement of tuned circuits.

Deviation of the carrier may be accomplished either electromechanically or electronically. The electromechanical method consists of mechanically varying the capacitance or the inductance of the oscillator tank circuit, causing the frequency to vary accordingly. The electronic method makes use of a reactance-tube modulator.

A sweep generator produces patterns containing a considerable number of instantaneous frequencies. It is necessary to introduce marker signals, which are superimposed on the trace, in order to orient bandpass characteristics (or center frequency) of the circuit under test with respect to frequency. The circuit which produces the marker signals may be an integral part of the instrument, or the marker signals may be supplied from an external source such as an AM signal generator coupled to the circuit being tested.

Most modern frequency-swept signal generators use a reactance-tube method of modulation, since this results in greater flexibility and the equipment is lighter and more compact than would be possible with the rotating capacitor.

The reactance tube and its associated components are connected across the tank circuit of the oscillator in the signal generator. In many cases the a-c powerline, which provides an excellent oscilloscope synchronizing medium, is coupled to the grid of the reactance tube to control the rate of the sweep. The reactance-tube modulator has an advantage over electromechanical modulators in the respect that it can be excited by an external variable AF signal generator, whereas the electromechanical modulator is usually limited to single-frequency operation.

MARKER GENERATOR

The marker generator consists essentially of an oscillator, the tuned circuit of which is normally damped heavily by the conductance of a control (or clamping) tube. This tube is cut off by a pulse, which is supplied by the enabling pulse generator, thus initiating the timing marker oscillations in synchronism with each sweep. The marker generator includes amplifying and pulse-shaping circuits and a rotary ganged switch which is used to change the circuit constants that determine the marker-pulse intervals, and also to shut off the marker generator. These sharp negative pulses are applied to the cathode of the cathode-ray tube. Each pulse makes the cathode more negative with respect to the control grid, and therefore intensifies the electron beam; hence, a series of bright timing dots is produced on the screen as the beam sweeps across. Since the marker generator is controlled by the enabling pulse, the first of each series of markers nearly coincides with the start of the sweep.

Synchronizing pulses which are obtained either internally (from vertical amplifier or trigger generator) or externally, enter the sweep channel by means of a sync selector switch and then pass through an amplifier to the enabling-pulse generator. This generator supplies square waves to energize the sweep and marker generators, and also supplies positive pulses to unblank the electron beam, which up to this time has been blanked by the negative voltage on the control grid of the cathode-ray tube. The enabling pulse passes to the sweep generator, where the basic voltage waveform (sawtooth) that sweeps the electron beam horizontally across the screen originates. The stability control is a screwdriver adjustment used to control the oscillating point of the enabling-pulse generator.

The trigger-pulse generator consists of a rate-governing continuous oscillator, an amplifier, and a pulse-generating circuit similar to a blocking oscillator but operating only (1 cycle at a time) under control of the rate-governing oscillator. When desired, this trigger generator supplies positive 25-volt 4-microsecond pulses for triggering external circuits at the rate of 300, 800, or 2,000 times per second. Simultaneously, through an internal connection, the trigger generator also provides similar pulses of lower amplitude for synchronizing the sweep circuit of the oscilloscope.

CATHODE-RAY OSCILLOSCO

The operation and operating con
general-purpose oscilloscope are di
Tradevman 3 & 2, NavPers 10376-A
strument is suitable for observation
forms in circuits involving low fr
However, as your work advances to
complex equipment involving much h
quencies, it becomes necessary to
complex test equipment.

OSCILLOSCOPE AN/USM-24C

An oscilloscope capable of display
forms found in the more complex
equipments is the AN/USM-24C.
USM-24C is a portable test set for
a luminous plot of time variations o
pulse or wave with self-contained
measuring its duration, displacement
stantaneous magnitude. The test se
of Oscilloscope OS-51/USM-24C,
accessories, and case cover CW-268/
The case cover has provisions for mo
accessories, and contains a schemati
of the instrument and storage spa
instruction book.

All operating controls and termi
OS-51/USM-24C oscilloscope are l
the oscilloscope's front panel and i
of the combination case as shown
4-6. The figure should be studied i
order to become familiar with the va
trols and terminals.

Voltage Limitations

Before using any oscilloscope,
portant that the repairman know the
mate voltage amplitude of the signa
served and the d-c voltage (steady s
of the test point. The maximum voltag
an oscilloscope is connected should ne
that recommended by the Operation I
Manual for the particular test instru
voltage limitations listed in table 4-
OS-51/USM-24C are typical for osc
of this type. The figures indicated
voltages which include not only the si
ponent but the steady state (d.c.) as v

In noting the figures in table 4-1
be remembered that the exact voltage
may be found in the appropriate ma
important to remember that by usin

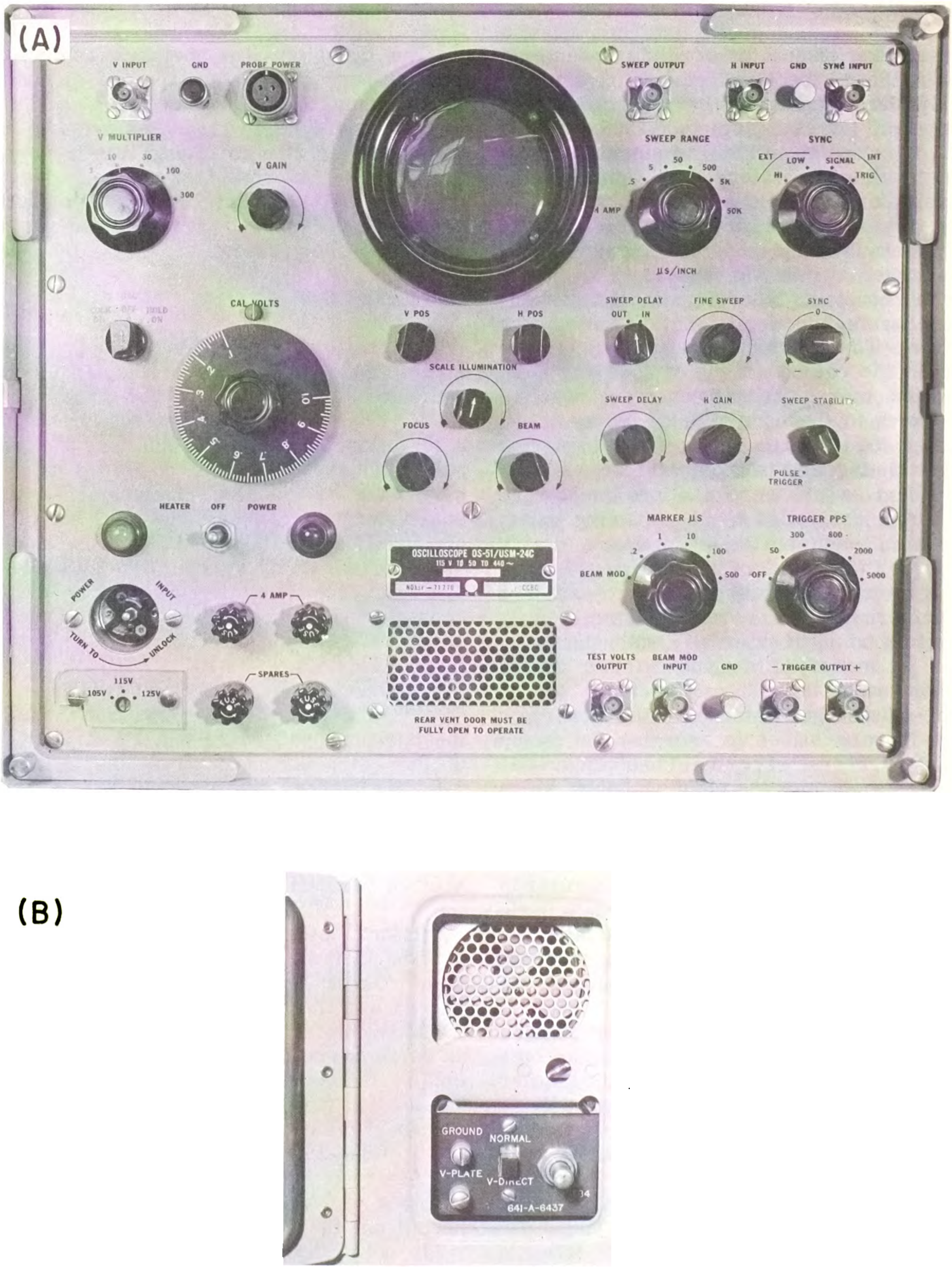


Figure 4-6.—Oscilloscope OS-51/USM-24C. (A) Front panel; (B) rear view.

Table 4-1.—Voltage limits.

Connector	Condition	Signal peak voltage	Total p volta
V INPUT		150	400
V INPUT	With Test Lead CG-883/USM-24C.	600	600
V INPUT	With Test Lead CG-944/AP.	2	400
V DIRECT		150	+600 -
H INPUT		40	400
SYNC INPUT		150	150
SYNC INPUT	With Test Lead CG-883/USM-24C.	450	600
BEAM MOD		50	400
BEAM MOD	With Test Lead CG-883/USM-24C.	450	600
TRIGGER PLUS			D-c cou
TRIGGER MINUS			+600 -

probes in connecting the inputs to the oscilloscope, voltages of a large range may be applied without damage to the equipment. In cases when it may become necessary to observe waveforms involving voltages in excess of those previously stated, a voltage divider may be used.

Waveform Observation

In the maintenance of electronic equipment, it is frequently necessary to observe waveforms at various test points within the equipment. First, in taking waveforms, it is necessary to prepare the oscilloscope and the equipment. The oscilloscope must be properly grounded to protect the operator from dangerous voltages that may result from a part breakdown. Next, the repairman must decide if the oscilloscope sweep is to be triggered or synchronized; if synchronized, he must decide whether to use external or internal sync.

To present a stationary pattern on screen of the oscilloscope, the time dura of the sawtooth sweep voltage must be equ or some multiple of the time duration of waveform to be observed. If this condition not exist, the observed waveform will ap to drift across the screen. The process which the beginning of the oscilloscope sv is adjusted to coincide with the beginnin the observed waveform is called sy synchronization.

Many times it is desired to observe n than 1 cycle of the input waveform. To do determine the time duration of the numbe cycles to be observed and adjust sweep duration accordingly (use μsec markers). example, to observe 4 cycles of a 500-kc sig the time duration of the sweep must be 8 μ

To observe waveforms utilizing the OS USM-24C, the controls must be set (assu that the oscilloscope has been adjusted for pr focus, beam position, and beam intensity, and the signal and sync test leads are connected to their respective connectors) as follows:

1. By means of the SWEEP RANGE switch and FINE SWEEP potentiometer, set the sweep time base to the proper range based on the number of cycles to be observed.
2. Set the SYNC selector switch to the desired synchronization source.
3. Set the H GAIN about halfway.
4. Rotate the SYNC control through its entire range and note the null point; set the control at this position. (NOTE: The null point is the point at which the horizontal sweep disappears.)

With the controls thus adjusted, the oscilloscope may be operated in the repetitive mode by rotating the SWEEP STABILITY control in a clockwise direction until a horizontal trace appears. To check your adjustment, slowly rotate the SYNC control through its null point. The horizontal trace should remain during this rotation.

To operate the oscilloscope in a triggered mode, set the SYNC control to the null point and rotate the SWEEP STABILITY control in a counterclockwise direction until the horizontal trace disappears. Check the adjustment by rotating the SYNC control away from the null point—the horizontal trace should reappear.

Once the mode of operation has been established by the proper setting of the SWEEP STABILITY control, the sweep can be controlled by the SYNC switch as indicated in table 4-2.

When it is necessary or desired to observe a particular portion of the trace, the SWEEP DELAY switch is turned to the IN position. This allows a 10 percent portion of the trace to be examined in detail. This 10 percent portion is expanded to occupy the full length of the screen which enables the SWEEP DELAY control to be adjusted until the desired portion of the trace appears on the screen of the CRT.

Table 4-2.—Sweep sync control settings.

SYNC switch position	Source of signal
INT-SIGNAL	Sweep internally synchronized or triggered by the signal.
EXT-LOW or EXT HI	Sweep externally synchronized or triggered. (NOTE: EXT-LOW is used if the synchronizing signal is less than 5 volts.)
INT-TRIG	Sweep synchronized or triggered from internal trigger generator. (NOTE: These pulses are highly accurate in frequency and are available at 50, 300, 800, 2,000,or 5,000 pulses per second as selected by the TRIGGER PPS switch.)

Voltage Measurements

The amplitude of any signal displayed upon the screen of the cathode-ray tube may be measured directly in peak-to-peak voltage by employing the calibration circuit contained in the oscilloscope. To measure the voltage amplitude of a signal, set the SWEEP RANGE switch to H AMP position to eliminate optical confusion in the horizontal plane. Turn the SCALE ILLUMINATION control clockwise until the scale divisions are plainly visible. Note the number of vertical divisions which the signal occupies. Hold the CAL switch in the ON position and adjust the CAL VOLTS control until the calibration signal occupies the same number of vertical divisions. The peak-to-peak voltage is the reading on the CAL VOLTS dial multiplied by the V MULTIPLIER switch setting. The waveform of the calibrating voltage is shown in figure 4-7.

It should be noted that the CAL VOLTS dial is calibrated in peak-to-peak voltage. If rms voltage is desired, the computed voltage must be divided by 2.83.

Time Measurements

The time duration of signals or portions of signals displayed on the cathode-ray screen may be measured by means of accurately timed marker pulses which appear as intensified dots along the trace as shown in figure 4-8. The marker pulses are generated in the oscilloscope and are available as follows: 0.2 μsec,

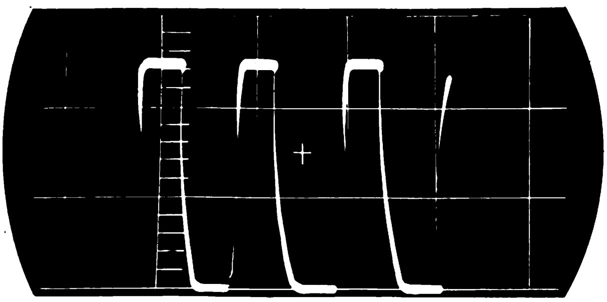


Figure 4-7.—Calibration voltage waveform.

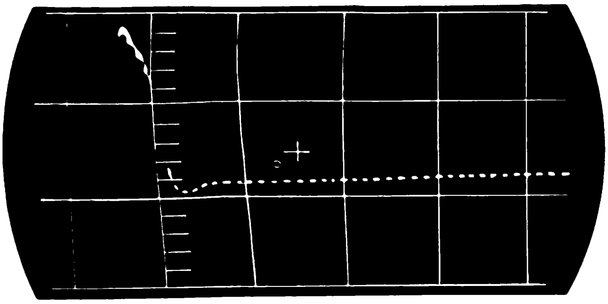


Figure 4-8.—Pulse and time markers.

1.0 μsec, 10 μsec, 100 μsec, and 500 μsec. However, the accuracy of time measurements is limited below 1.0 μsec. The markers are applied to the trace by setting the MARKER μS switch to the appropriate range and adjusting the BEAM control until the markers are clearly defined.

Accessory Probes

Two types of probes are furnished with the USM-24C. They are Attenuating Probe CG-883/USM-24 and Test Lead CG-944/AP. The attenuating probe is frequency-compensated, has a 10 to 1 attenuation which introduces a loss of 10 to 1, and increases the input impedance by 10. It is employed when the input signal to the vertical, horizontal, synchronization, or beam modulation channels is so large as to cause overdrive and distortion of the signal. The shunt capacity is 9 μμf (also called picofarad) and the input impedance is 3 megohms.

The tip may be replaced with a 6-32 screw for short connections. The probe may be used to reduce total capacitive effect on a circuit under test. When two of these probes are used together with connector UG-274/U (a T connector), sufficient isolation is provided to permit mixing 2 voltages at the oscilloscope in o
to portray them simultaneously. The probe
be connected to the V INPUT, H INPUT, S
INPUT, CAL VOLTS, and BEAM MOD
nectors. The ground clip should be conne
to the chassis of the equipment under test
the probe tip to the point to be measure
to which voltage is being supplied.

If very high level signals are to be m
ured which, when attenuated by the V MU
PLIER and probe combined, are still abov
voltage safety limit of the V INPUT, a vol
divider such as Voltage Divider TS-89B/AP
be used to decrease the signal. This wil
effect, extend the oscilloscope range in
cordance with the factors of attenuation prov
by the voltage divider.

Test Lead CG-944/AP has an inte
grounded plate amplifier with low loss.
probe assembly has an input impedance
megohm shunted by 8 μμf and can handle
ages up to 2 volts rms. Figure 4-9 sho
schematic diagram of the probes. The tr

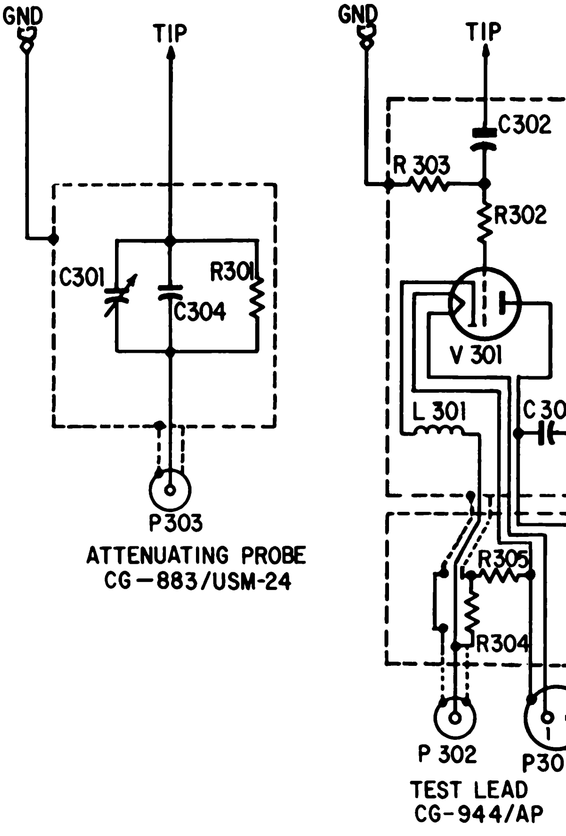


Figure 4-9.—Accessory probes CG-883/
USM-24 and CG-944/AP.

V301 is a subminiature tube, with the load appearing in the cathode circuit. L301 is a peaking coil to neutralize the effect of cable capacity in the bandpass. The signal is connected to the oscilloscope through P302, and power for the test lead is obtained through P301. This probe is employed where the signal under test is small and the circuit cannot stand the oscilloscope's shunting effect of 300,000 ohms and 37 $\mu\mu$f. The probe's 2 connectors are attached to the V INPUT and PROBE connectors of the oscilloscope. The main purpose of the probe is for observation in circuits without loading them unduly.

Maintenance

The useful life of this oscilloscope can be extended by using normal care when handling and operating it. Insofar as it is practicable, it should be protected from dust and extremes in temperature. When not in use, the power should be disconnected from the oscilloscope, unless climatic conditions require the use of the heater. (The unit should remain connected to the power source and the power switch left in the HEATER position when humidity conditions range from 75 to 95 percent.)

When storing the unit, replace the accessories in their proper locations and place the cover on the oscilloscope. When in use, the area behind the oscilloscope should be clear to permit the free flow of air through the rear ventilating door. If the rear ventilating door can be opened fully (approximately 4 inches), there will be enough air space in the rear of the oscilloscope for proper operation.

To insure proper ventilation the air intake grill on the front panel and air exhaust grill inside the rear vent door must be kept clean at all times. The grills may be kept clean by wiping the inner and outer surfaces with a damp, soft cloth.

Both the graph screen and cathode-ray-tube face must be kept free of dust, which tends to collect on charged surfaces. Clean the cathode-ray-tube face with a clean damp cloth and dry the tube thoroughly. The graph screen may be cleaned with any detergent. Do not use alcohol, acetone, kerosene, gasoline, carbon tetrachloride, or paint thinner.

No parts of the oscilloscope require periodic lubrication. The blower motor is lubricated at the factory for the life of the motor. Potentiometer shafts which bind may be lubricated sparingly with oil such as MS 2075.

Electronic maintenance of the USM-24C is straightforward and should present no unusual problems. A large percentage of maintenance will probably consist of replacement of tubes, calibration, and alinement. Instruction Book for Oscilloscope AN/USM-24C, NavShips AN16-30USM24-3, presents detailed operating and maintenance instructions.

Figure 4-10 is a simplified block diagram of the USM-24C oscilloscope. It is suggested that you become thoroughly familiar with the block diagram.

HIGH-PERFORMANCE OSCILLOSCOPES

The advent of higher operating frequencies and the ability to develop pulse waveforms of extremely short rise and fall times (10 nanoseconds (0.01 μsec) is not uncommon), have given rise to a need for an oscilloscope that can faithfully reproduce these waveforms. This requires an O-scope with a flat frequency response over a wide range of frequencies (d.c. to 14 megacycles or better). Figure 4-11 shows the AN/USM-105A which has been developed for the Navy to fulfill these needs.

This scope features simplicity of operation by the use of simplified, logically grouped controls and a high degree of flexibility with the use of plug-in units. It utilizes a 5-inch CRT with a calibrated-grid overlay (called a graticule). This graticule is 10 cm long by 6 cm high, marked in centimeter squares with 2 mm subdivisions on the horizontal and vertical axes. The horizontal sweep time control is calibrated in time per cm and the vertical sensitivity controls are calibrated in volts per cm. Thus, the display on the scope face may be read directly in volts and time. (Frequency is found by taking the reciprocal of time; that is, $f = 1/t$.)

Another important feature of the USM-105A is the dual trace vertical amplifier. This is a plug-in unit and enables the scope to present two signals simultaneously for easy comparison.

INTERPRETATION OF OSCILLOSCOPE PATTERNS

One of the most important steps in waveform analysis—the one which usually proves the most difficult for personnel inexperienced with oscilloscope work—is the proper interpretation of the patterns viewed on the oscilloscope screen. It should be borne in mind that

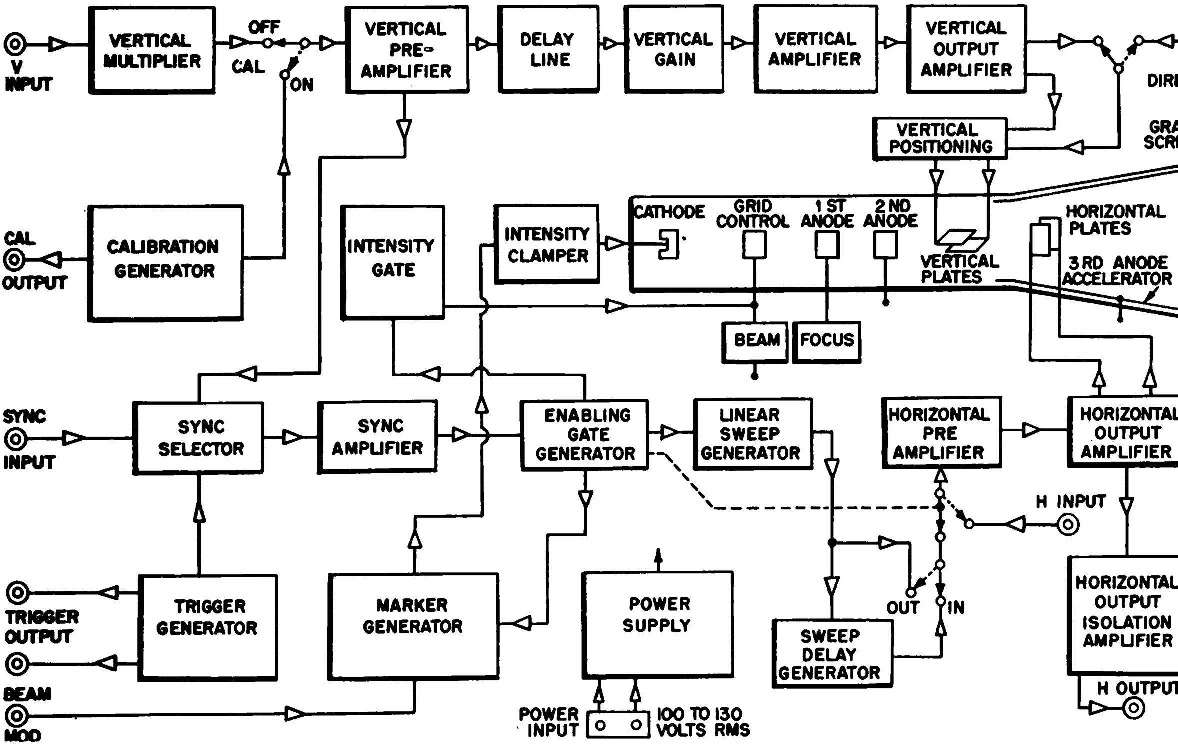


Figure 4-10.—USM-24C, block diagram.

the unknown signal is always plotted as a function of a signal whose characteristics are known. If the characteristics of the signal on one axis are not known, then it will be almost impossible to identify or interpret the signal under investigation on the other axis. For this reason, it is generally common practice to use on the horizontal axis a sawtooth (or sinusoidal) waveform of a known frequency which is synchronized with the fundamental or some integral submultiple of the frequency under test.

Since the sawtooth waveform gives horizontal deflection which is linearly proportional to time, it provides a plot of the wave shape of the unknown signal versus time. Whether the observed pattern is a true reproduction of the signal under test is largely determined by the limitations of the particular oscilloscope available for use. The basic oscilloscope is limited by the following circuit characteristics, which are inherent in the test equipment's frequency response and sensitivity of both the vertical and horizontal amplifiers; namely, phase distortion, input impedance, and the maximum permissible input signal.

Frequency Comparison

Measurement of frequency can be
plished with the oscilloscope by compa
unknown frequency with a standard or
frequency. The procedure involves the
tion of Lissajous patterns on the oscill
These patterns, or figures, are traced
screen when the linear sweep voltage is s
off and sine-wave voltages are applied
the horizontal and to the vertical de
plates.

Waveform Distortion

For purposes of discussion, wavefor
be considered, as simple (consistin
fundamental sine wave) or complex
harmonic content, such as a sawtooth or
wave). When both simple and complex
forms pass through an amplifying circui
a definite frequency response, their outpu
forms are affected (distorted) in a d
manner. The sine wave can suffer only
of amplitude, whereas the complex wa
because of its harmonic content, can be di

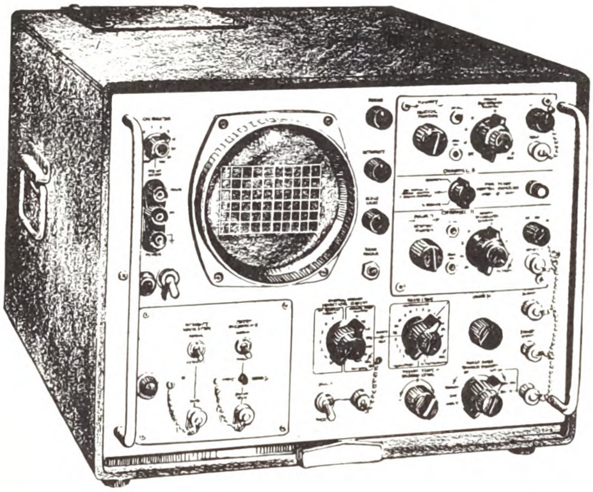


Figure 4-11.—AN/USM-105A oscilloscope.

in both amplitude and wave shape. Therefore, when viewing waveforms having harmonic content, the repairman must consider the frequency response of the amplifiers in the oscilloscope being used.

The horizontal amplifier is used to amplify a sawtooth waveform, the frequency of which varies broadly. Because of the harmonic content of this waveform, it is possible that a nonlinear (distorted) sweep may develop at the horizontal output, becoming more pronounced as the frequency increases. For this reason, signals under observation should be viewed on the fundamental and on several integral submultiples of the sweep voltage. The resultant single, double, triple, etc., presentations should be compared with each other, and the pattern which provides the best linearity should be used.

The frequency response of the vertical and horizontal amplifiers of the basic oscilloscope (OS-8/U) described in Basic Electronics, NavPers 10087-A, extends from about 5 cycles per second to 100 kc. Since this frequency response has proved inadequate for many test applications, an oscilloscope having a frequency response extending from 5 cycles per second to 2 megacycles is now considered as a general-purpose oscilloscope. For true reproduction and proper evaluation of complex waveforms, a synchroscope having special circuits for pulse analysis is used. This type of oscilloscope has a very broad frequency response, extending from about 3 cycles per second to 11 megacycles.

When a complex waveform is passed through an RC network (usually coupling), some of the harmonic components may develop a time lead with respect to the other components. This change in the waveform is known as phase distortion, and is most pronounced at either end of the amplifier response curve. If the RC coupling network contains a variable resistor (gain control), the degree of phase distortion of a particular frequency varies, depending upon the setting of the control. At the lower frequencies the resistance of the potentiometer is the determining factor; at the higher frequencies the inherent distributed capacitance of the rotor affects the phase relationship of the harmonic components. Insofar as the oscilloscope is concerned, only complex waveforms are affected by phase distortion. While it is true that a simple (fundamental) waveform may develop a time lead or lag, the resultant wave shape is unaltered.

Stray pickup may be another cause of waveform distortion. To avoid such pickup, make the leads from the circuit under test as short as possible. In some cases the pickup may be so disturbing that it is almost impossible to use an oscilloscope. A few things can be done to reduce the effect of stray fields on the oscilloscope: First, the cathode-ray tube itself must be very carefully shielded. In most cases, this shielding is provided by the aquadag coating within the tube and also by a metallic shield surrounding the outside of the tube. Second, the common side of the oscilloscope circuit should be connected to a ground point in the circuit under test and also to a good external ground connection, to eliminate most of the stray voltages that are picked up by the leads. Third, a low-capacitance coaxial cable may be used to reduce still further the effect of stray fields.

Procedure for Waveform Observations

Use of the oscilloscope to observe wave shapes when tracing signals is especially indispensable when circuits contain more than one type of signal. This is true when observing composite signals which contain synchronizing pulses and video information on the same transmitted carrier. At different horizontal sweep frequencies the oscilloscope will allow the various composite signals to be displaced. A TD should be familiar enough with the equipment under test to know approximately what type of wave shape to expect, its approximate frequency, and at what point in the circuit.

The oscilloscope is one of the most valuable and dependable test instruments. However, you must be able to interpret the information before any use can be made of it. Use the oscilloscope and use it correctly. An Operation Instruction Manual is provided with each type of oscilloscope used by the Navy. Obtain one for the particular oscilloscope you are to use and study it thoroughly.

SPECIAL OSCILLOSCOPE CIRCUITS

Oscilloscopes designed for the analysis of pulse waveforms are calibrated in terms of time and voltage for the horizontal and vertical axes, respectively. Voltage calibrations are conducted by means of an attenuator at the input of the vertical amplifier and by a signal-generator circuit that produces a known level, or controlled levels of voltage which may be used for reference. The horizontal, or time, axis is marked for selected intervals of time by precisely spaced pulses that produce either vertical lines, or if injected into the cathode or grid circuit of the cathode-ray tube, cause intensification or deintensification of the trace at given time intervals.

Calibration Generator

The calibration generator uses a gas-filled VR type voltage-regulator tube in conjunction with an intermittently operated relay to provide a continuous square-wave output of relatively low frequency (approximately 100 cycles) and of controllable amplitude (0.1 volt to 1 volt). Whenever the multiplier switch (fig. 4-12) is turned to the calibration position, the chosen calibrating voltage is impressed on the signal input of the vertical amplifying system, so that the deflection per volt at this point can be determined for any setting of the gain control. Since this point of calibration is inside the oscilloscope at the output of the multiplier, the voltage of the signal at this point must be multiplied by the ratio of voltage increase back to the signal input. This ratio is a fixed quantity for each multiplier setting, and is marked beside the corresponding switch position. A probe containing an L-pad extends the voltage range to 450 volts, at the expense of a 10-to-1 reduction in sensitivity. Use of an external voltage divider will further extend the voltage range.

CRYSTAL TEST SET MODEL 390A

MIXER

The Mixer Crystal Test Set, Model 3 (fig. 4-13) is designed to give accurate ind tions of crystal quality. The accuracy and simplicity of this test set make it a valu aid in maintaining optimum performance of high-frequency equipments and especially th types which utilize balanced mixer crystals

Theory of Operation

The quality of a mixer crystal can be termined by measurement of its conversion and noise temperature. Conversion loss is fined as the ratio of the power available f the RF signal source to the power availabl the IF output of the crystal. Noise tempera is defined as the ratio of the IF noise po available from the crystal to the thermal n power available from a resistance (equa the IF resistance of the crystal) at r temperature.

The design of the mixer crystal test se based on the fact that the minimum conver loss and noise temperature can be determ from the degree of nonlinearity of the st voltage current (E-I) curve of a mixer crys The mixer crystal test set measures this r linearity by measuring the incremental cha in crystal current caused by an increme change in voltage applied to the crystal in ''forward'' direction. The adjustment tha made to variable resistor R101 (fig. 4-14) CAL-TEST switch S101 in the CAL posi is such that, if the E-I curve of the cry being tested were linear, a midscale rea would be obtained on meter M101 when S was switched to the TEST position. If the re ing obtained is below midscale, the E-I curv the crystal is nonlinear. The amount by wh the reading falls below midscale is a meas of the degree of nonlinearity; the lower meter reading is below midscale, the m nonlinear is the E-I curve of the crystal, the lower are its conversion loss and n temperature.

Figure 4-14 is a schematic diagram of mixer crystal test set. The initial adjustn of voltage V1 is made by variable resistor R with CAL-TEST switch S101 in the CAL posit Fixed resistors R102, R104, R105, and R determine the limits to which V1 can be adjus

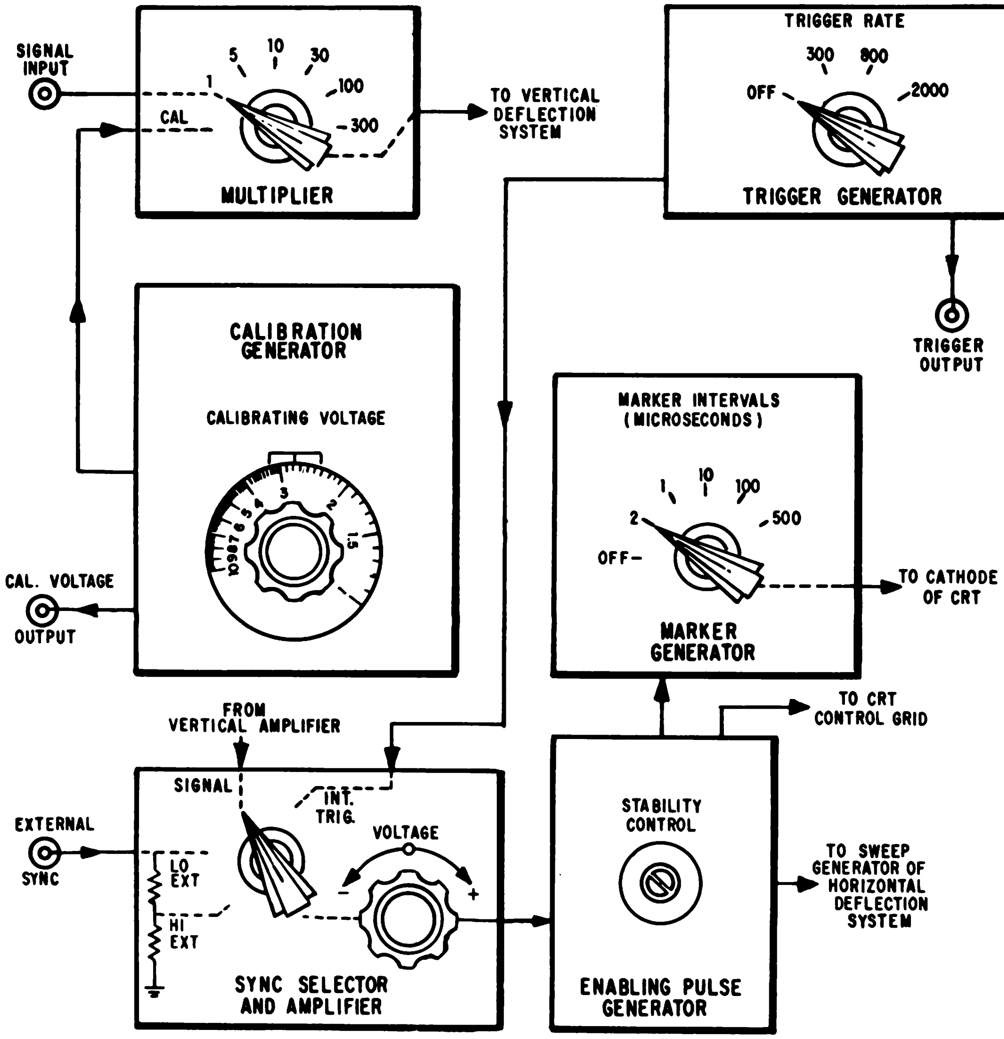


Figure 4-12.—Special oscilloscope circuits used for pulse analysis; block diagram.

The voltage increment (Δe) is established by resistors R103 and R107 when S101 is placed in the TEST position; it has the same value for all crystals.

When a crystal is to be tested, it is placed in crystal holder X101. (The crystal should be handled by the base, and any static charge should be removed by touching the base to the grounding spring on the crystal holder while inserting the crystal.) S101 is placed in the CAL position, and R101 is adjusted until the indication on microammeter M101 coincides with the calibration scale reading of R101. When S101 is placed in the TEST position, M101 indicates the quality of the crystal. With the aid of figure 4-15, the reading of M101 in the TEST position can be converted to actual conversion loss and noise temperature. Black-and-white block sections on the meter scale facilitate acceptance or rejection of crystals according to the type being tested.

An incorrect adjustment of variable resistor R101 may cause excessive voltage to be applied to microammeter M101, which in turn will damage the pointer. Therefore, before moving CAL-TEST switch S101 to the CAL position, set variable resistor R101 fully clockwise.

EQUIPMENT LIMITATIONS

The mixer crystal test set is used to determine the conversion loss and noise temperature

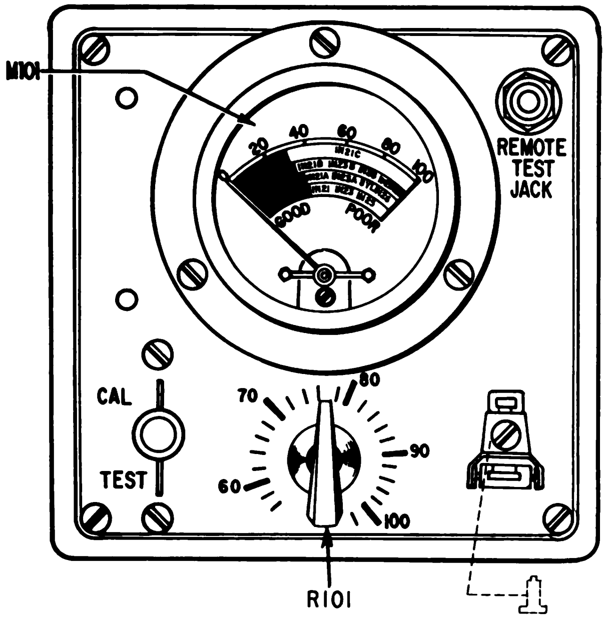


Figure 4-13.—Mixer Crystal Test Set, Model 390A.

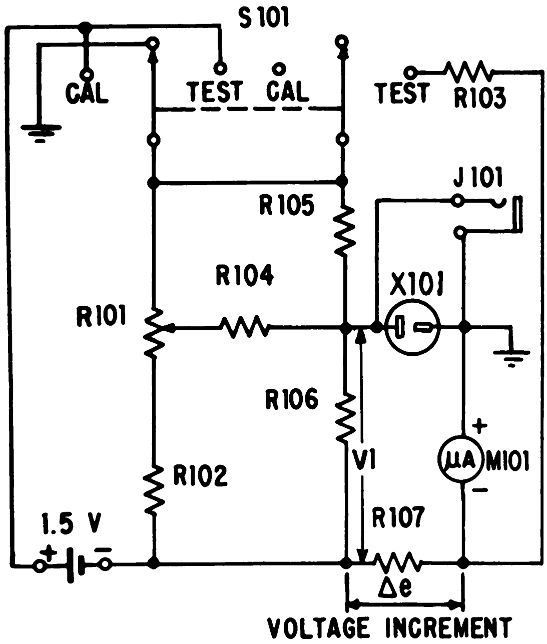


Figure 4-14.—Mixer crystal test set, schematic diagram.

of mixer crystals intended for use at 10,000 megacycles or below. For crystals used above 10,000 megacycles, the readings are still relative—that is, crystals can still be selected in the order of their quality.

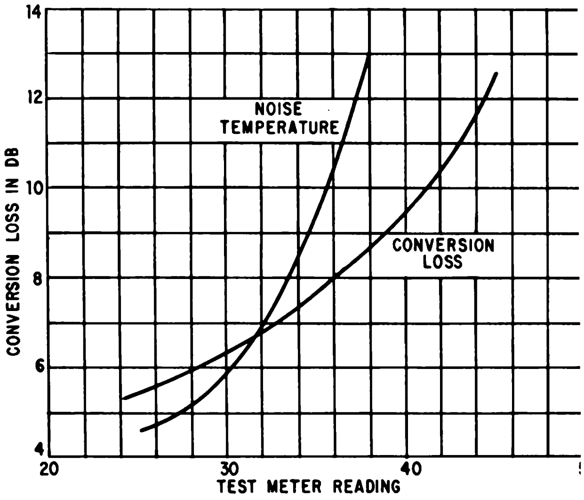


Figure 4-15.—Calibration chart.

TESTING CRYSTALS OF OPPOSITE POLARITY

Mixer crystals of opposite polarity ca tested by using an adapter that reverses position of the crystal in the crystal holde the mixer crystal test set. Another metho to attach test leads to a telephone plug in remote test jack, and make connections to crystal by means of clips on the test lea observing proper polarity.

CHECKS AND ADJUSTMENTS

If it is not possible to obtain suffic pointer deflection, or if the meter pointer cre down-scale while the CAL-TEST switch is the CAL position, the dry-cell battery is proba exhausted and should be replaced. Always move the dry-cell battery from the equipm before it is stored for periods of more tha day or two.

If the meter pointer is positioned off-z at the leading edge of the scale, adjust the z corrector to return the pointer to zero.

If the meter pointer flickers back and fo while the CAL-TEST switch is in the CAL po tion, the crystal holder contacts may be b broken, or dirty. Clean the contacts or repl the crystal holder. Repairs other than th are generally considered beyond the scope operating personnel.

IN-CIRCUIT TRANSISTOR CHECKER

Test Set, Transistor TS-1100/U (fig. 4-16) is designed to measure the beta parameter of a transistor when the transistor is connected in a circuit, and to measure beta and I_{CO} parameters with the transistor removed from the circuit.

The characteristics of the test set are:

1. Range of beta: $10 < \beta < \infty$ in a single band.
2. Leakage current measurements: $0 < I_{CO} <$ 50 microamperes.
3. Temperature range: 0 C to +50 C.
4. Power supply: Battery operated.

The equipment contains two separate battery power supplies. One provides the power for the internal circuits, and the other furnishes the bias voltage required for the transistor under test. Either the mercury type or zinc-carbon batteries may be used for operation of the test set.

Low-impedance techniques are used for measurement to isolate the transistor under test from the surrounding circuity. The measurement accuracy of the tester is within ±20 percent provided that the loading of the emitter-base diode or the collector-base diode is not below 500 ohms, and the loading between the collector and the emitter is not below 500 ohms. If the emitter-base load contains a diode, the series impedance must not fall below 7,000 ohms to maintain this accuracy.

With the use of an appropriate shorting technique, the accuracy can be improved. The shorting technique consists of connecting a jumper wire between the emitter of the transistor under test and the far side of all components connected to the base electrode of the transistor. This technique is not universally applicable, and it should be employed only by skilled personnel.

The range of beta that can be measured is between 10 and ∞. A beta of infinity corresponds to zero microamperes on the readout meter scale. A transistor having a beta below 10 will cause the pointer of the meter on the tester to move off the scale. Because of the nonlinear characteristic of the meter scale, which causes crowding at the high end, the readout accuracy for betas above 100 is impaired.

The following controls, as seen on the front panel (fig. 4-16), are incorporated in the test set:

1. POWER switch (labeled ON-OFF): Turns the internal power source on or off.
2. PNP-NPN (transistor select) switch: Selects the proper collector bias polarity for the type transistor under test.
3. BETA switch: Permits readout of beta.
4. BIAS SELECT switch: Used to set the proper collector bias voltages (nominally 3, 6, or 12 volts). Also checks the condition of the internal battery when in the TEST position.
5. REDLINE SET control: Adjusts the amplitude of the test signal.
6. SHORT switch (labeled CB-CE, BE): Enables measurement of a short circuit or a low impedance in the collector-base (CB), collector-emitter (CE), or base-emitter (BE) circuits.
7. I_{CO} switch: Enables readout of transistor leakage.
8. SHORT indicator: The indicator lamp will light when a short circuit or low impedance exists in either the transistor under test or in the surrounding circuitry. If the lamp lights, this indicates a load of less than 500 ohms.
9. TEMPERATURE indicator: The indicator lamp will light when the ambient temperature surrounding the equipment exceeds +50 C. This indicates that the equipment is operating in an environment beyond that for which it has been designed, and that measurement inaccuracies will arise.
10. METER: Indicates magnitude of beta; indicates magnitude of I_{CO}; and indicates the condition of the internal battery. (The battery is good when the meter needle moves under the green band on the dial.)
11. PROBE connector: For connecting the cables (furnished with test set) to the transistor to be tested.
12. TRANSISTOR socket (labeled E-B-C): Enables direct connection between the test set and transistor to be tested.
13. BATTERY DISCONNECT switch (upper left corner of panel—not labeled): Disconnects the internal battery when the front cover is snapped in place.

For proper procedure in operating the test set, refer to Technical Manual for Test Set Transistor TS-1100/U, NavShips 93277.

OVERALL FUNCTIONAL DESCRIPTION

The block diagram (fig. 4-17) consists essentially of a reference oscillator, a tuned amplifier, and a variable bias supply. The oscillator is used to generate a test signal, the tuned amplifier is used to measure the second harmonic component of the current of

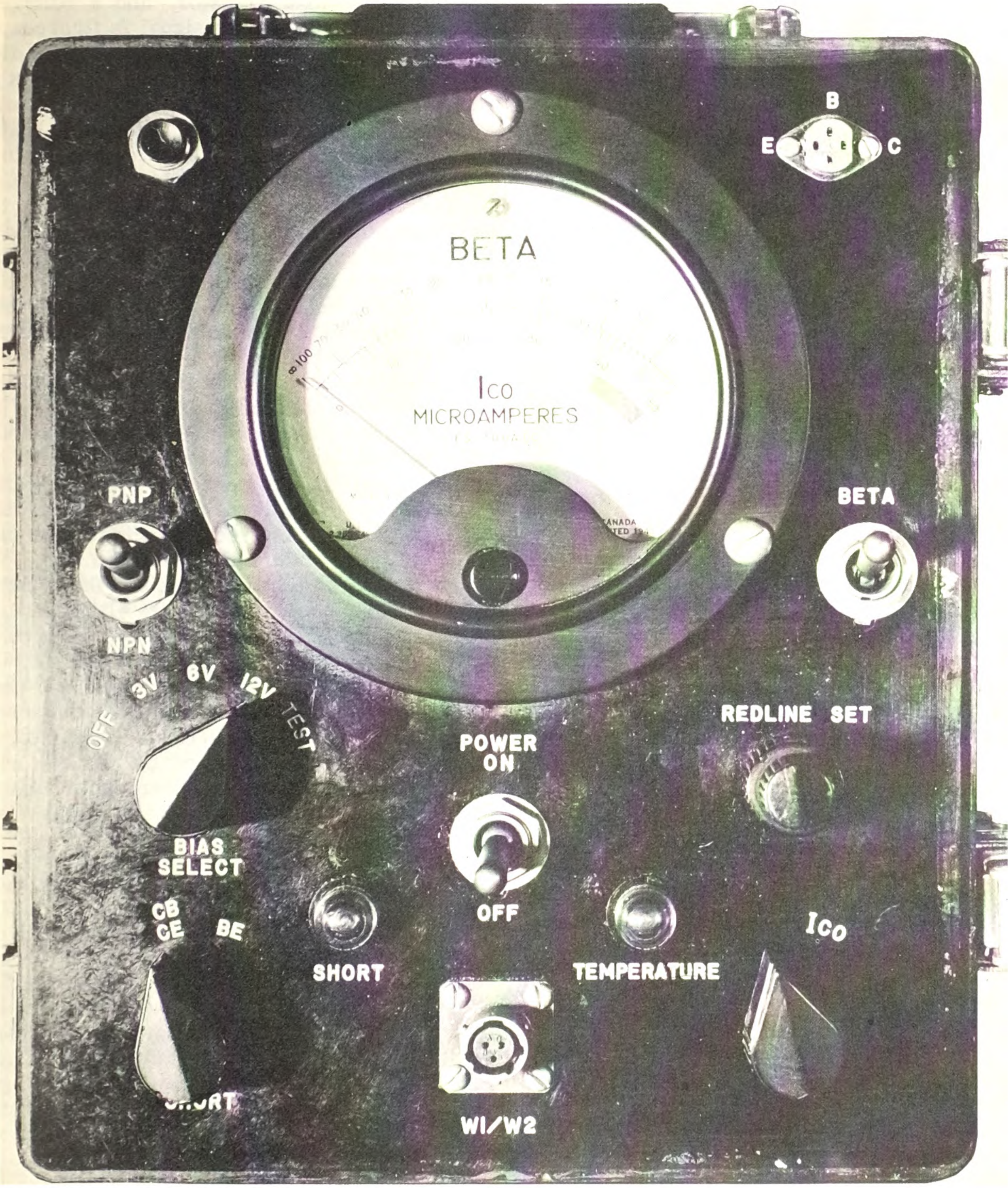


Figure 4-16.—Test Set, Transistor TS-1100/U.

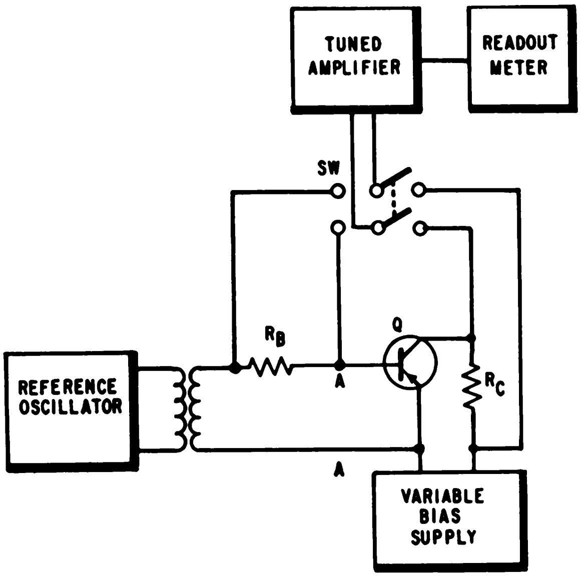


Figure 4-17.—TS-1100/U, block diagram.

the transistor under test, and the bias circuit furnishes the appropriate voltages to the transistor under test.

The reference signal source is a Hartley oscillator operating at a frequency of 1,125 cycles per second. The transistor under test is biased for approximately class B operation. Thus, the transistor conducts only when the input signal level exceeds the work function of the emitter-base diode. The input signal is adjusted until the average collector current is 1 milliampere. The current passes through the collector load resistor, and a voltage is developed across it. This signal is first coupled through a high-gain, narrowband amplifier, having a center frequency of 2,250 cycles per second, and then through a d-c microammeter. The amplifier gain has been adjusted so that the red line on the meter face corresponds to an average collector current of 1 milliampere.

The bandpass amplifier and meter are then switched across the base load resistor, and the meter then reads the magnitude of the average beta directly for a given transistor. Since the collector current is held constant for all transistors under test, the base current is inversely proportional to beta.

Direct measurement of the average collector and base current cannot be made on a d-c meter placed in series with these electrodes. This is because of the large errors which may result from the presence of "sneak paths" provided by the external network, since it is possible to have a direct current flow in these paths from the collector bias supply.

By making an a-c measurement, the problems of erroneous direct current are eliminated, but others are introduced. If the a-c components of the collector current and base current were measured without filtering, the readout meter would not be able to differentiate between the normally rectified signal of the transistor and a nonrectified signal caused by the a-c sneak paths. To eliminate these erroneous signals, the second harmonic component of the signal current is measured.

CHAPTER 5

PRINCIPLES OF AIR CONDITIONING

The term "air conditioning" is often erroneously construed to mean the cooling of a given mass of air. When correctly defined, it is the process of treating air so as to control its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space. It can be stated that true air conditioning requires mechanical ventilation, addition of heat, removal of heat, control of humidity conditions, and filtering.

The construction and operation of most electronic equipment require controlled temperature and humidity conditions. To obtain the desired atmospheric control from air-conditioning equipment requires space, a source of power, and routine maintenance. Training devices, because of their limited space, usually utilize compact units. This normally increases the maintenance requirements of the equipment. The most widely accepted configuration for training devices is the self-contained air-conditioning unit. That is, complete air handling, cooling, heating, humidifying, and dehumidifying equipment are designed to fit into one compact package.

This chapter and the following chapter are intended to provide the TD with a general knowledge of air conditioning and types of air-conditioning systems used in training and training devices. Subjects discussed include a review of the physics of heat, fluids, and gases. Air-conditioning requirements, theory of operation, and maintenance are also discussed. Air-conditioning equipments will vary from trainer to trainer, but the general theory will remain the same.

HEAT

One of the most common things encountered by man is heat. Heat, in its broadest sense, is a form of kinetic (in motion) energy found in the random motion of molecules, which will raise the temperature of the body to which it is added. The heat energy withi is increased, and its temperature the molecules of a substance are that their rate of motion is increase

Heat is classified into two dis sensible heat and latent heat. Se is heat which can be sensed by to thermometer. It is the energy req change in temperature, such as a c 80° to 90° F.

BRITISH THERMAL UNIT

The standard used to measure is the British thermal unit (Btu). defined as the amount of heat requi the temperature of 1 pound of pure Temperature and heat must not b Temperature is an indication of th or heat intensity of a substance. Un conditions, however, heat can be substance without a corresponding temperature. (See fig. 5-1.)

LATENT HEAT

Latent heat or hidden heat i required to bring about a change i of matter. Since pure water was u standard for establishing the Btu, used to explain latent heat (fig. substances do not have the same of vaporization (vaporization and co and fusion (freezing and melting compared to it through the use

Water boils at 212°F; however 1 pound of water into 1 pound of ste an increase in temperature) requi dition of 970 Btu. To change this into water requires the removal of 9 changing of a liquid to a gas, or is referred to as the latent heat of v (vaporization and condensation) of w

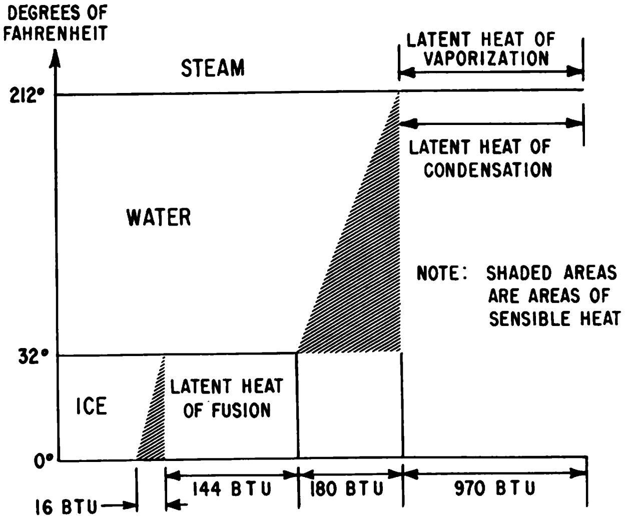


Figure 5-1.—Simple heat diagram.

The amount of heat that must be removed to change 1 pound of water (at 32°F) to 1 pound of ice (at 32° F) is 144 Btu. To melt this same ice requires the addition of 144 Btu. This changing of a liquid to a solid, or vice versa, is referred to as the latent heat of fusion (freezing and melting respectively) of water. (The change of the state of heat is discussed in greater detail later in this chapter.)

SPECIFIC HEAT

The term used to express the capabilities of a substance to react to heat by changing its temperature is specific heat. Specific heat is defined as the amount of heat required to raise 1 pound of a substance 1 degree F.

Referring to the shaded areas of figure 5-1, it can be seen that this can be used for computations when no changes of state of matter are involved. It requires 180 Btu to raise the temperature of 1 pound of water from 32°F to 212° F, or a 180-degree change. The ratio of 1 to 1 for water gives it a specific heat of 1. However, it requires only 16 Btu to raise the temperature of ice from 0°to 32°F; a change of 32 degrees. This means that it required only 0.5 Btu to raise 1 pound of ice 1 degree F; thus, the specific heat of ice is 0.5.

HEAT TRANSFER

Heat can be transferred in any one of three methods, conduction, convection, and radiation. Each is discussed separately in the following paragraphs.

Conduction

Metal transmits heat more easily than wood because it is a better conductor of heat. Different materials conduct heat at different rates. Some metals are better conductors of heat than others.

Figure 5-2 shows an example of the different rates of conduction of various metals. Four rods of different metals have several wax rings hanging on them. The rings drop off from the copper rod first, then from the aluminum rod, then from the nickel rod, and last from the iron rod. This example shows that of the four metals used, copper is the best conductor of heat, and iron is the poorest.

Liquids are poorer conductors of heat than metals. Notice that the ice in the test tube of figure 5-3 is not melting rapidly even though the water at the top is boiling. The water conducts heat so poorly that not enough heat reaches the ice to melt it.

Gases are even poorer conductors of heat than liquids. This may be attributed to the fact that conduction is actually a process whereby the increase in molecular energy is transmitted by actual contact. Because the molecules are farther apart in gases than in solids, the gases are much poorer conductors of heat.

Materials that are poor conductors are used to prevent the transfer of heat and are called heat insulators. Certain materials such as finely spun glass and a mineral named asbestos are particularly poor heat conductors. These materials are therefore used for most types of insulation where there is a difference in ambient (surrounding) temperatures.

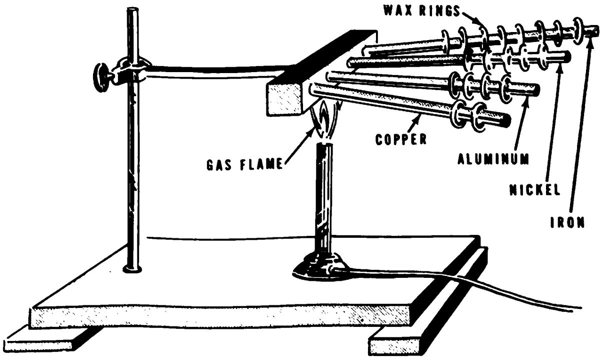


Figure 5-2.—Various metals conduct heat at different rates.

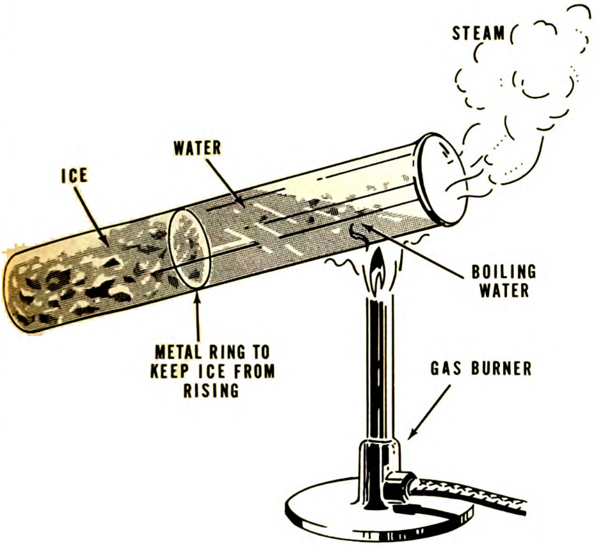


Figure 5-3.—Water is a poor conductor of heat.

Convection

Of the three principal methods of heat transfer, only convection requires motion of matter. Convection is the process in which heat is transferred by moving a heated substance. For example, an electronic tube (fig. 5-4) becomes hotter and hotter until the air surrounding it begins to move. The motion of the air is upward which carries the heat away from the hot tube (by convection).

Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot object (such as a vacuum tube) can also be increased if it is provided with copper fins that conduct heat away from the hot object. The fins provide large surfaces against which cool air can be blown.

A convection process may take place in a liquid as well as in a gas. Figure 5-5 shows a transformer in an oil bath. The hot oil is less dense, has less weight per unit volume, and rises, while the cool oil falls, is heated, and rises in turn.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps are used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water to help cool large equipment. In most electronic installations electric fans and blowers are used to aid convection.

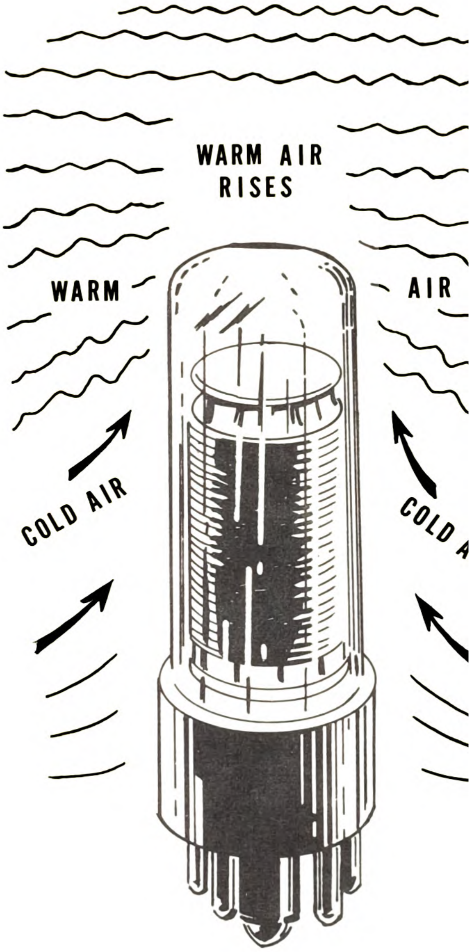


Figure 5-4.—Vacuum tube cooled by co

Radiation

Another process of heat transfer i
when considering how the earth der
heat from the sun. Since no mediur
through which conduction or convecti
take place, it must be assumed that t
heat is transferred by another meth
means of heat transfer is referre
radiation.

The term radiation refers to the c
emission of energy from the surfac
bodies. This energy is known as radian
Most forms of energy can be traced
the energy of sunlight. Sunlight, in the
electromagnetic heat waves, travels gr
tances to reach the earth. These elec
netic heat waves are absorbed when th

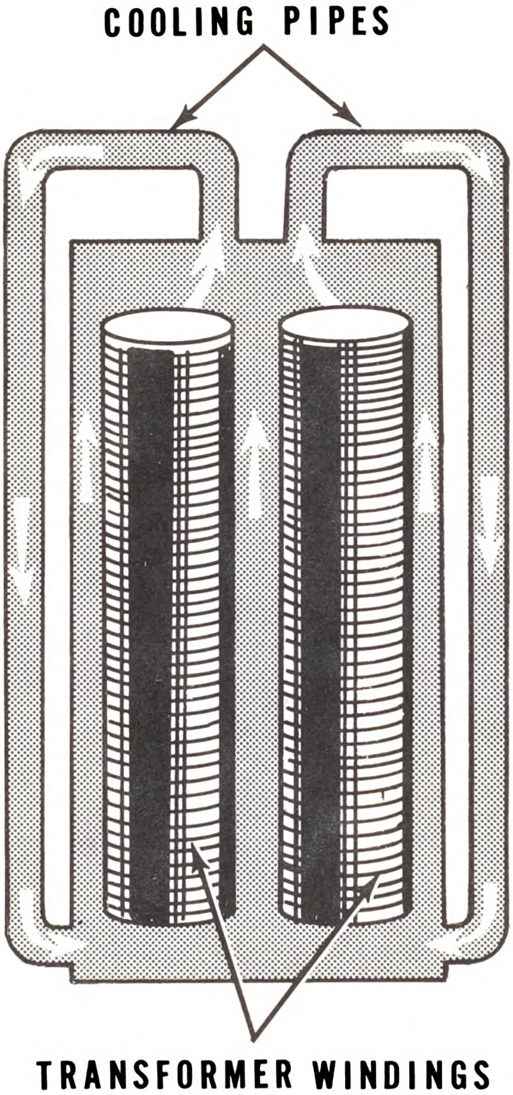


Figure 5-5.—Oil convection currents cool a transformer.

in contact with nontransparent bodies. The net result is that the motion of the molecules in the body is increased as indicated by an increase in the temperature of the body.

The differences between conduction, convection, and radiation are considered. First, although conduction and convection are extremely slow, radiation takes place with the speed of light. This fact is evident at the time of an eclipse of the sun when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light. Secondly, radiant heat may pass through a medium without heating it. For example, the air inside a greenhouse may be much warmer than the glass through which the sun's rays pass. Thirdly, although conducted or convected heat may travel in roundabout routes, radiant heat always travels in a straight line. For example, radiation can be cut off with a screen placed between the source of heat and the body to be protected.

RADIATORS AND ABSORBERS.—The sun, a fire, and an electric light bulb all radiate energy. However, a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. Bodies which do not reflect are good radiators and good absorbers, and bodies that reflect are poor radiators and poor absorbers. A practical example of the control of loss of heat is the thermos bottle. The flask itself is made of two silvered walls of glass with a vacuum in between. The vacuum prevents the loss of heat by conduction and convection and the silver coating prevents the loss of heat by radiation.

CHANGE OF STATE OF HEAT

Notice that a thermometer placed in melting snow behaves in a strange manner. (See fig. 5-6). The temperature of the snow rises slowly until it reaches 0 degree C. Providing the mixture is stirred constantly, it remains at that point until all the snow has changed to water. A definite amount of heat is required to change the snow to water which is called the heat of fusion. This heat changes the water molecules from crystal form to liquid form. (NOTE: Heat of fusion was discussed earlier in this chapter.) The heat which is absorbed while the ice is melting represents the work required to produce the change of state.

Many substances react the same as water. At a given pressure, they have a definite heat of fusion and an exact melting point. Many materials however, do not change from a liquid to a solid state at one temperature.

HEAT OF VAPORIZATION

As discussed earlier in this chapter, heat must be added to water to change it to steam with no change in temperature. If a given quantity of water is heated until it evaporates—that is, changes to a gas—a much greater amount of heat

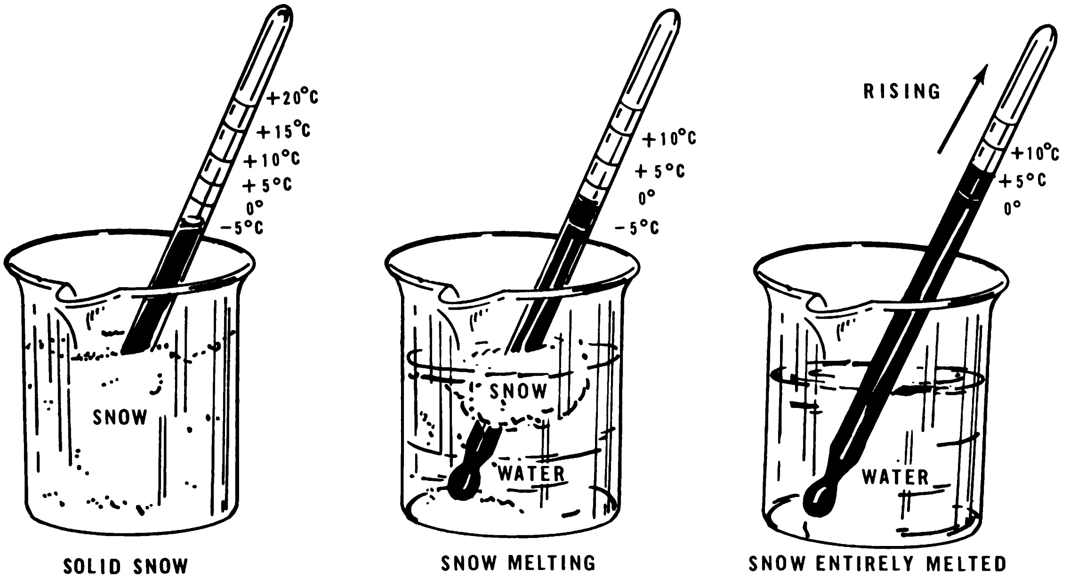


Figure 5-6.—Observing the temperature of melting snow.

is used than that which is necessary to raise the same amount of water to the boiling point. For example, it takes 970 Btu to change 1 pound of water at 212°F to water vapor (steam) at 212° F. The amount of heat that is necessary for this change is called the heat of vaporization of water.

To provide effective cooling, a refrigerant must pass through a change of state from liquid to gas. To accomplish this, the temperature of the liquid must be raised to its boiling point. When the refrigerant boils, it absorbs heat from the surrounding air (latent heat).

Table 5-1 lists several common refrigerants as compared to water.

Table 5-1.—Boiling point of refrigerants at 15 psia.

Refrigerant	Boiling point	Latent heat
Water	212° F	970 Btu
Carbon tetrachloride	169° F	90 Btu
Sulphur dioxide	14° F	167 Btu
Freon-12	-21° F	72 Btu
Ammonia	-27° F	588 Btu

REFRIGERATION

Primitive man used snow, ice, and cold water as a method of preventing the rapid spoilage of food. These methods are still in use today by campers and persons lost in the wilderness.

Refrigeration became a commercial enterprise when ice from frozen lakes and rivers was cut and stowed in insulated rooms. The ice, in the form of large cubes, was then sold to the consumer, who in turn used an insulated icebox to keep his food edible. In 1834, Jacob Perkins constructed the first successful ice-making apparatus. His machine proved to be the forerunner of our modern compression systems. Shortly afterward the first absorption type refrigeration mechanism was produced. Both methods are still in use today.

In 1918, Kelvington made automatic home refrigerators available to the public. General Electric Co. produced a "sealed" automatic refrigeration unit in 1926. One year later, the first automatic refrigeration unit for home cooling was placed on the market.

REFRIGERATION TON

The heat transfer capabilities of a refrigeration unit are normally measured in units of refrigeration tons. A 1-ton unit is capable of removing the amount of heat necessary to melt 1 ton of ice at 32° F in 24 hours. Since the latent heat of fusion for water is 144 Btu per pound, the melting of 1 ton of ice (2,000 lb) requires 288,000 Btu (144 x 2,000 = 288,000).

Small refrigeration units are rated in Btu's per hour. It is a simple matter to convert the Btu rating to refrigeration tons by methods used in the following example. The data tag on a particular unit shows the unit is rated at 12,000 Btu per hour. To convert to tons, multiply 12,000 Btu by 24 hours:

12,000 X 24 = 288,000 Btu per day, or 1 ton

Other units may be rated in terms of horsepower which has nothing whatsoever to do with heat transfer capabilities of the unit. This indicates compressor motor rating only. The Btu rating of a 1-horsepower unit is normally less than that of a 1-ton unit.

TEMPERATURE SCALES

Temperature measurement may be defined as the measurement of thermal potential. An object which is hot to the touch can be said to have a high temperature when compared to the human body. In other words, temperature is used as a measure of the heat relationship of an object in relation to some standard.

THERMOMETERS

The most common thermometer depends upon the expansion of liquid such as mercury for the indicating means. Still other methods of measurement may be obtained by utilizing such techniques as changes in pressure of a gas, changes in the electrical resistance, the expansion of metal, and so forth. Regardless of the methods employed to obtain a standard of measurement, there are only four scales commonly utilized in thermometry. These scales are the Fahrenheit, centigrade, and their absolute values, the Rankin and Kelvin. A comparison of the four scales is depicted in figure 5-7.

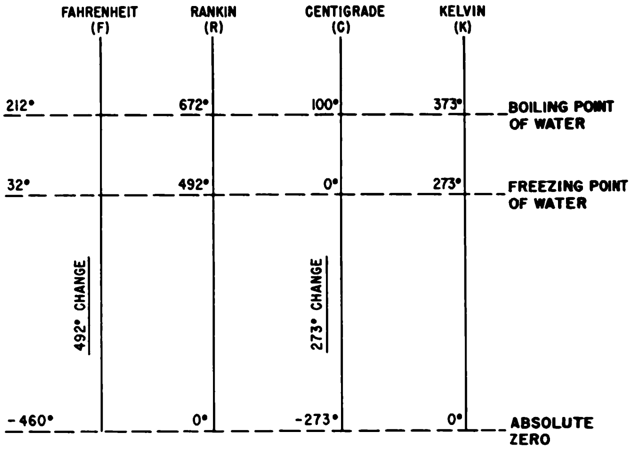


Figure 5-7.—Temperature scales.

A detailed study of figure 5-7 will reveal the following:

1. To convert degrees Fahrenheit to degrees Centigrade, subtract 32 degrees and multiply by 5/9.
2. To change degrees Centigrade to degrees Fahrenheit multiply by 9/5 and add 32 degrees.
3. To convert from degrees Centigrade to degrees Kelvin, add 273 degrees.
4. To change degrees Fahrenheit to degrees Rankin, add 460 degrees.

Using the above information the TD should be able to convert to any desired scale.

Because the range of all liquid thermometers is extremely limited, other methods of thermometry are necessary. Among the most widely used types of thermometers other than the standard liquid thermometers are the resistance thermometer, and the thermocouple.

The resistance thermometer makes use of the fact that the resistance of metals changes as the temperature changes. This thermometer is usually constructed of platinum wire wound on a mica form and enclosed in a thin-walled silver tube. It is extremely accurate from the lowest temperature to the melting point of the unit.

The thermocouple (fig. 5-8) is essentially an electric circuit that makes use of the principle that when two unlike metals are joined and the junction is at a different temperature than the remainder of the circuit, an electromotive force is set up. Thermocouples can be located at any point in a machine where the temperature is important.

EXPANSION

Nearly all substances expand or increase in size when their temperature increases. A

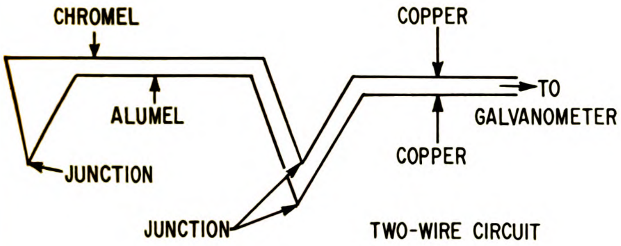


Figure 5-8.—Thermocouple.

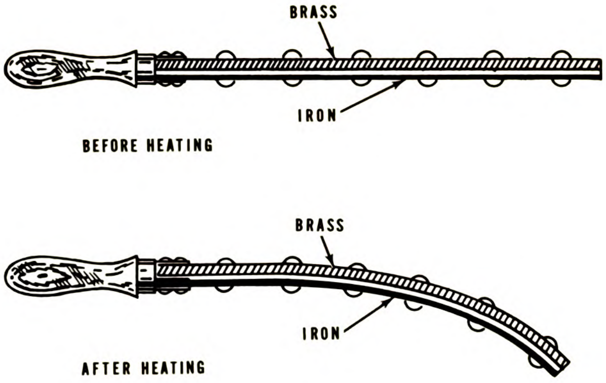


Figure 5-10.—Compound bar.

good example of the expansion and contraction of substances is the ball and ring illustrated in figure 5-9. The ball and ring are made of iron and when they are both the same temperature the ball barely slips through the ring. When the ball is heated or the ring is cooled, the ball will not slip through the ring.

Experiments have shown that for a given change in temperature, the change in length or volume is different for each substance. The amount that a unit length of any substance expands for a 1-degree rise in temperature is known as the coefficient of linear expansion for that substance. With few exceptions, the coefficient of expansion is positive.

A practical application based on the difference in the coefficients of linear expansion of dissimilar materials is the thermostat. This instrument consists of an arrangement of two strips of dissimilar metals fastened together so that when the temperature increases, a bending takes place due to the unequal expansion of the metals (fig. 5-10). Thermostats based on this principle are used in overload relays for motors and temperature-sensitive switches. (See fig. 5-11.)

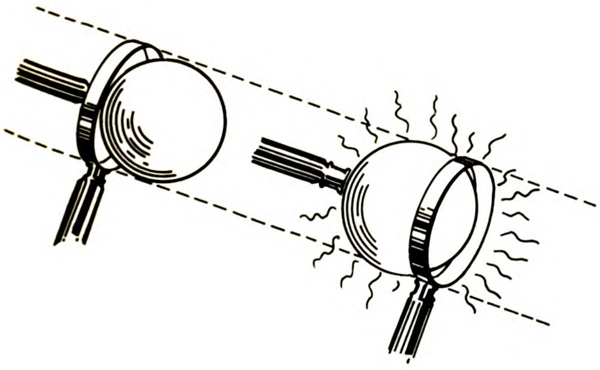


Figure 5-9.—Ball and ring.

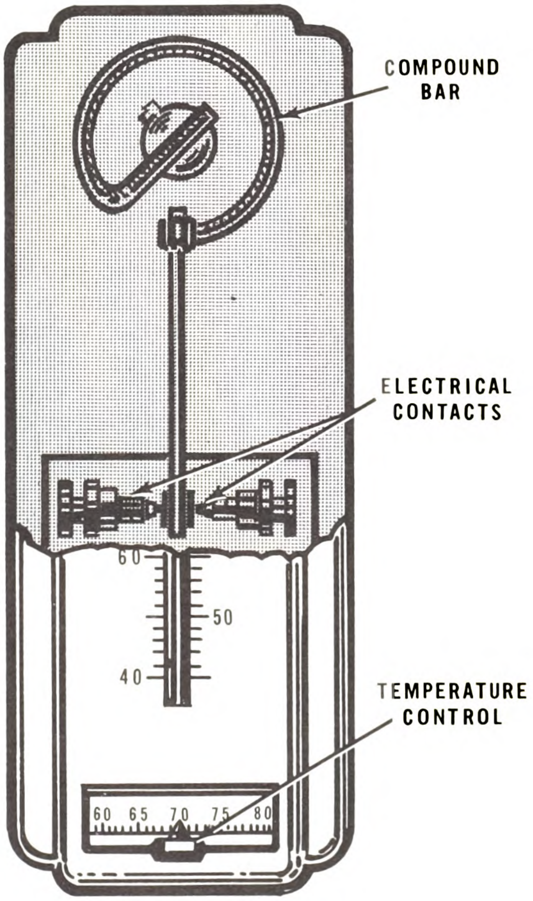


Figure 5-11.—Thermostat.

PRESSURE

Force may be defined as an influence which produces, or tends to produce, motion or change of motion. In other words, force is a push or pull action. Pressure is the measured amount of force per unit area and is usually expressed as pounds per square inch (psi).

If a force of 100 pounds were exerted against a surface of 50 square inches, pressure applied can be found by dividing the area into the force; hence the formula, $P = F/A$.

$$P = \frac{100 \text{ lb}}{50 \text{ sq in.}} = 2 \text{ psi}$$

Atmospheric pressure is the force per unit area exerted on a body due to the weight of the airmass itself. The average atmospheric pressure at sea level is considered to be 14.7 psi. This figure is usually rounded off to 15 psi for computation purposes.

For ease of interpretation, refrigeration pressure gages are calibrated to read zero at standard sea level pressure. Indications taken directly from this gage are called gage pressures (psig). Absolute pressure indications would indicate the gage pressure plus atmospheric pressure. To convert gage pressure to absolute pressure (psia) add 15 to gage pressure. For example, the pressure gage reading of 3 psig equals 3 + 15 or 18 psia.

Pressures less than atmospheric pressure are termed vacuums. A perfect vacuum may be described as -15 psig or 0 psia. Vacuums, however, are usually expressed as inches of mercury (Hg). Each inch of mercury vacuum is equal to -0.5 psi with a maximum of 30 inches. As an example, a pressure gage which reads 15 inches Hg vacuum (15 x -.5) equals 7.5 pounds less than zero atmospheric, or 7.5 psia.

HUMIDITY

The term humidity is used to describe the presence of moisture or water vapor in the air. Absolute, or specific humidity, is the actual amount of moisture present in the air, measured in grains per pound of dry air (1 grain is equal to 1/7,000 of a pound).

Relative humidity is the term used to express the amount of moisture in a given sample of air, in comparison with the amount of moisture the air would hold if saturated. Based on calculations, 1 pound of dry air at 85°F is capable of containing 183 grains of moisture. If this same airmass contained 61 grains, its relative humidity would be 33 percent. Relative humidity is determined by dividing the amount of moisture that could be contained in the airmass into the amount that is actually present. The lower the percentage of relative humidity (the drier the air), the more comfortable the human being normally feels (below 30 percent some people will become uncomfortable).

up to this point in the discussion it might be assumed that only decreasing the temperature and relative humidity are of importance in specifying a desirable indoor-air condition. Everyone has experienced the cooling sensation of air in motion, whether that air motion was the result of natural winds or was created by a desk fan. How air motion provides a cooling effect may be better understood if one knows something about the manner in which the human body loses heat to its environment.

The body loses heat to its surroundings by any of the following means:

1. By radiation of heat if the body surface is at a higher temperature than the surrounding surfaces to which the body is exposed. Under summer conditions where the room surfaces are warm, little heat transfer can take place between the body and the room surfaces.
2. By convection to cool air next to the body. The rate at which heat is convected away by the air depends on the temperature as well as the velocity of the air moving over the skin.
3. By evaporation of moisture from the skin and lung surfaces. When air is moved across the skin surfaces, the saturated air next to the skin is replaced by drier air and the cooling effect is increased because more moisture is evaporated.

The air-conditioning system must therefore not only control the temperature of the spaces, but it must either remove (dehumidification) or add moisture (humidification).

Air is said to be saturated when it can absorb and hold no additional moisture. As the airmass is cooled, contraction takes place, and like a wet sponge being squeezed, some of the moisture is given up in the form of condensation. The temperature at which condensation takes place is called the dewpoint.

An example of moisture condensation is the dehumidification action in the air conditioner. A cold fluid of some kind (refrigerant), not necessarily water, is passed through a cooling coil (evaporator), which is built much like an automobile radiator since the fluid is inside the coil and air passes over the outside of the coil. When moist, warm air is passed over the outside of the coils, the temperature of the air is reduced causing moisture to condense on the cooling fins. Then water begins to condense out of the air as the air is cooled, gathering on the outside of the coil, and then this moisture is passed off through a drainage system.

SIMPLE HEAT DIAGRAM

The cooling of the air in the above example, is accomplished by the fluid in the coil absorbing heat (Btu) from the air. The fluid inside the coil is called the refrigerant. A good refrigerant should be capable of absorbing a great amount of heat with little rise in its own temperature. One of the common refrigerants is Freon gas. A simple heat diagram for Freon is shown in figure 5-12. This diagram shows that when the temperature of Freon, in the liquid state, is changed to a gas at -21° F (boiling point) it will absorb 72 Btu. This means that for every pound of Freon that completes a cycle of operation in the system, 72 Btu can be absorbed from the air passing over the cooling coil (evaporated).

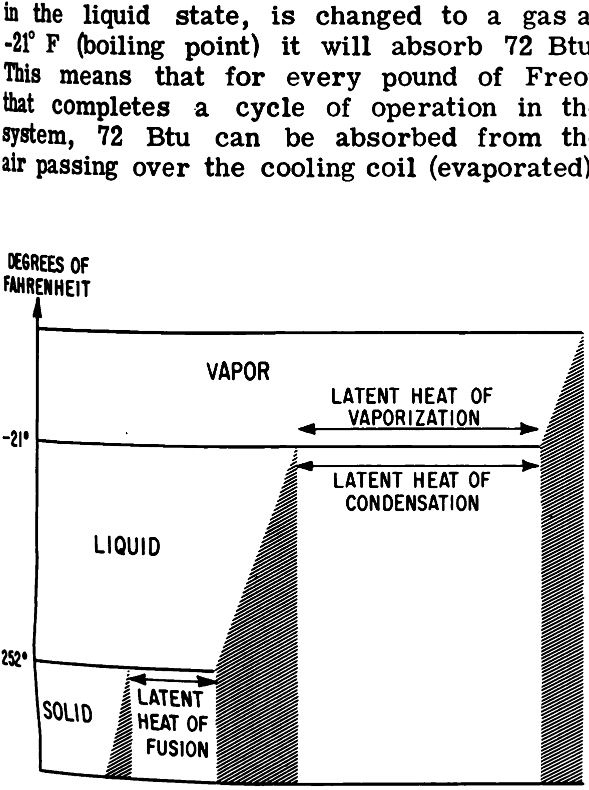


Figure 5-12.—Simple heat diagram, Freon.

GAS LAWS

THE KINETIC THEORY OF GASES

Like pressure, the temperature of a ga can be measured with respect to an absolut zero value. This value was established ex perimentally during a series of tests made i the study of the kinetic theory of gases.

A gas, like other forms of matter, is com posed of molecules, or small particles made u of combinations of atoms. Normally, the mole cules of any substance are in constant motio In the gaseous state, the motions are assume to be entirely random. That is, the molecule are free to move in any direction and are i constant collision, both among themselves an with the walls of the container. The movin particles possess energy of motion, or kineti energy, the total of which is equivalent to th quantity of heat contained in the gas. Whe heat is added, the total kinetic energy is in creased. When the gas is cooled, the therma agitation is diminished and the molecular veloc ities are lowered.

The molecules do not all have the sam velocity (not even in the same gas), but displa a wide range of individual velocities. Th temperature of the gas, according to the kineti theory, is determined by the average energ of the molecular motions. Pressure is ac counted for by considering it as resultin from the bombardment of the walls of th container by the rapidly flying molecules.

In accordance with the kinetic theory, the heat energy of a given gas sample coul be reduced progressively, a temperature woul be reached at which the motions of the mole cules would cease entirely. If known wit accuracy, this temperature could then be take as a natural reference, or a true absolut zero value. If the temperature of the gas i raised the molecules move faster and th pressure rises. The more gas that is pumpe into a container of constant volume, the greate the number of molecules there are to bombar the walls and the greater is the resultan pressure.

The basic laws governing gases can be ex pressed in simple formulas stating the genera relations of volume, pressure, and tempera ture. One of the most important of thes principles concerns the relation of gas volum to pressure. It has been known since th seventeenth century and is associated wit the name of Robert Boyle, an English scientist of that time who first announced it.

BOYLE'S LAW

Boyle was among the first to study what he called the "springiness of air." He learned by direct measurement that if the temperature of an enclosed body of gas is kept constant, the volume is reduced to half the former value when the pressure is doubled. As the applied pressure decreases, the resulting gas volume increases; or in general, the product of the volume and pressure remains constant. Boyle formulated the general law which can be stated as follows:

When the temperature is held constant, the volume of any dry gas varies inversely with the applied pressure.

This can be expressed in equation form in two ways:

$$V_1P_1 = V_2P_2, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where
V1 and P_1 refer to the original volume and pressure, and V_2 and P_2 refer to the new volume and to the new pressure which causes it.

As discussed earlier in this chapter gas pressure may be indicated in one of two ways—absolute pressure or gage pressure.

In connection with volume and pressure, consider the following problem which involves Boyle's law. Nitrogen is confined in a container with a volume of 2 cubic feet. The pressure is 150 psi (gage). If the gas is allowed to expand to a volume of 10 cubic feet with no change in temperature, what is the new value of the gage pressure?

The gage reading must first be converted to absolute pressure by adding the atmospheric pressure (add 15 psi to the gage pressure). The resulting value, the original volume, and the new volume are then substituted in the formula:

$$V_1P_1 = V_2P_2$$

$$(2)\ (150+15) = (10)\ (P_2)$$

$$P_2 = \frac{(2)\ (165)}{10}$$

$$P_2 = 33 \text{ psia}$$

Converting absolute to gage pressure

33 - 15 = 18 psi, gage pressure; answer.

CHARLES' LAW

This law consists of two general statements which relate the temperature of a gas to (1) the volume with the pressure held constant, and (2) the pressure with the volume constant. The principle is named in honor of a French physicist, whose studies provided much of the foundation for the modern kinetic theory of gases. Charles found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. Expressed in equation form, this part of the law is given by

$$V_1T_2 = V_2T_1, \text{ or}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

where

V_1 and V_2 refer to the original and final volumes; and T_1 and T_2 indicate the corresponding temperatures.

EXAMPLE: Five cubic feet of gas at 37°F is raised to 90° F at a constant pressure. What is the new volume? (Temperature must be expressed in absolute value.)

V_1 = 5 cu ft $\qquad$ T_2 = (90°F + 460)

T_1 = (37°F + 460) $\qquad$ V_2 = unknown

$$5(90 + 460) = V_2\ (37 + 460)$$

$$5(550) = 497V_2$$

$$2750 = 497V_2$$

$$V_2 = 5.53 \text{ cu ft}$$

Since the volume of a gas increases as the temperature rises, it is reasonable to expect that if a given mass of gas were heated, and yet confined in the same space, the pressure would increase. In equation form, this part of Charles' law becomes:

$$P_1T_2 = P_2T_1, \text{ or}$$

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

In words, this states that with constant volume, the pressure of any gas varies directly with the absolute temperature.

THE GENERAL GAS EQUATION

The facts concerning gases discussed in the preceding sections are summed up and illustrated in figure 5-13. Boyle's law is expressed in (A) of the figure; the effects of temperature changes on pressure and volume (Charles' law) are illustrated in (B) and (C), respectively.

By combining Boyle's and Charles' laws, a single expression can be derived which states all the information contained in both. This expression is called the General Gas Equation, a very useful form of which may be expressed as follows:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

It can be seen by examination of figure 5-13 that the three equations it contains are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals T_2 and both these can be eliminated from the general formula, which then reduces to the form shown in (A). When the volume remains constant V_1 equals V_2, thereby reducing the general equation to the form given in (B). Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in (C).

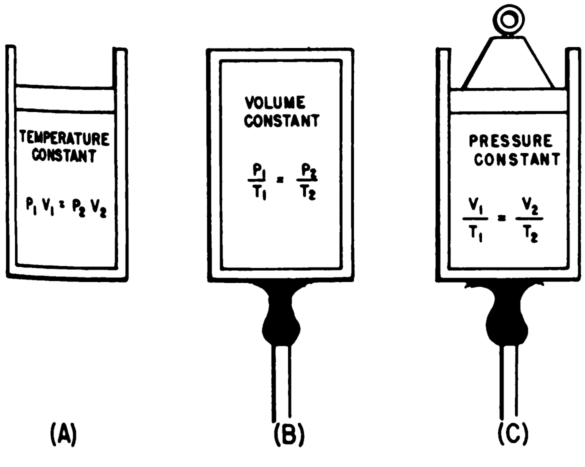


Figure 5-13.—The general gas law.

REFRIGERANTS

The system which provides mechanical cooling is commonly referred to as the refrigeration system. The refrigeration system, whether it is a part of an air conditioner, a refrigerator, water cooler, or numerous commercial installations, operates on the same general principle using a refrigerant.

Mechanical refrigeration systems use as the primary refrigerant some liquid that has a boiling point lower than water, but that, in changing from liquid to vapor at low pressures and temperatures absorbs a lesser quantity of heat. Most refrigerants commonly used today require close-to-atmospheric pressures in the system, and thus leaking tendencies and overwork of compressors are reduced to a minimum.

FREON-12

Dichlorodifluoromethane is known variously as Freon-12, Genetron 12, or Isotron 12. In some texts, you will find it referred to as Refrigerant-12, or R-12. In other training courses, it is generally called Freon-12. It has a boiling point of minus 21.7° F, and would immediately boil if exposed to ordinary room temperature and atmospheric pressure. It must therefore be kept under pressure, if it is to be maintained in a liquid state; and this pressure will vary according to the ambient temperature. Its freezing point (minus 247° F), is a temperature not likely to be encountered in operating conditions.

Freon-12 has now replaced to a great extent such refrigerants as ammonia, sulfur dioxide, or methyl chloride, which because of their toxic and explosive character have caused many fatalities.

The chief advantages of this refrigerant are:

1. It is odorless and tasteless in concentrations of less than 20 percent by volume in air.
2. It is nontoxic; but by reducing the oxygen content in a working space, it can cause suffocation.
3. It is nonexplosive and nonflammable; although it decomposes in the presence of an open flame, forming irritating and toxic gases, it will not ignite.
4. It is noncorrosive in contact with the metals that are commonly employed in refrigeration units; it will, however, corrode magnesium, and aluminum alloys that contain magnesium.
5. It is chemically stable up to at least 1,000°F; above that temperature, it decomposes, forming corrosive and poisonous products.

6. It acts as a solvent, loosening and removing particles of dirt, scale, or oil within the system. However, it will eat away natural rubber gaskets, so neoprene or some other synthetic rubber must be used.

7. It mixes readily with oil, and thus simplifies the lubrication of the plant by acting as a carrier of oil to moving parts, and as an aid in returning the oil from the evaporator. This last characteristic is important, since an excess of oil in the evaporator will form an insulating film between the refrigerant and the inside surface of the evaporator.

The disadvantages of Freon-12, from an operating standpoint, are as follows:

1. It has a low latent heat, and as a result, absorbs only about 51 Btu for every pound of refrigerant that boils off in the evaporator at 5° F, when condensing temperature is 86° F. This low latent heat necessitates the circulation of a large volume of refrigerant per ton of refrigeration.

2. In concentrations of 20 percent or more, Freon-12 produces a phosgene gas if exposed to an open flame.

3. In its liquid form, Freon-12 can cause severe frostbite. Extra care must be taken to avoid this; since the refrigerant has no noticeable odor, leaks may escape notice.

The disadvantages of the low latent heat (51 Btu per pound of refrigerant) can be emphasized by comparing it with the refrigeration ton (12,000 Btu per hour). Thus a 1-ton unit would have to boil off a minimum of approximately 235 pounds of refrigerant per hour to maintain the cooling capacity of 12,000 Btu per hour.

Another point to remember is that, because of the capacity of Freon-12 to absorb water, utmost caution is necessary to prevent the entrance of water (or water-laden air) into the system. Any excessive moisture in the system can cause freezeups at the expansion valve. This characteristic is one that Freon-12 shares with all refrigerants whose boiling point is below 32° F.

REFRIGERATION CYCLE

OPERATION

As the refrigerant flows through the primary (or basic) refrigeration components, it assumes four different and distinct states of character. These four states of refrigerant (fig. 5-14) are as follows:

1. Low pressure gas (input side of the compressor).
2. High pressure gas (output side of the compressor).
3. High pressure liquid (output side of the condenser coil and liquid receiver).
4. Low pressure liquid (output side of the expansion valve).

After passing through the evaporator coil the refrigerant returns to a low-pressure gas, and the cycle is repeated until the unit is shut off. The following sequence of operation traces the flow of refrigerant through its cycle and explains where the changes take place.

When the compressor starts, it draws refrigerant gas from the low-pressure (suction) side of the refrigeration system. Mechanical action of the compressor changes the refrigerant into a high-pressure gas. This gas is normally cold when it enters the compressor, but it becomes hot during compression.

The hot high-pressure gas leaves the compressor's high-pressure (discharge) side and flows directly to the condenser coil. The heat produced when the gas was compressed and the heat removed from the conditioned space is dissipated with a finned coil by the airstream drawn through this coil by the condenser fan. This cooling effect starts the high-pressure gas changing into a high-pressure liquid.

From the condenser coil, the refrigerant flows to the receiver which acts as a reservoir for storing the liquid refrigerant. After leaving the receiver, the high-pressure liquid flows through the thermostatic expansion valve. Here the refrigerant is changed into a low-pressure liquid and is metered into the evaporator coil.

Upon entering the evaporator coil, the low-pressure liquid changes (boils) to a low-pressure gas. This change, from liquid to gas, produces a cooling effect within the evaporator coil and the coil becomes cold. A stream of air is directed over the cold coil. The air is cooled and then directed to the space to be cooled.

After leaving the evaporator coil, the refrigerant returns to the low-pressure (suction) side of the compressor.

The foregoing cycle is repeated as long as the compressor is operating. As can be seen from the above, the flow of refrigerant is from the compressor to the condenser coil, then to the receiver, to the expansion valve, to the evaporator coil, and back to the compressor.

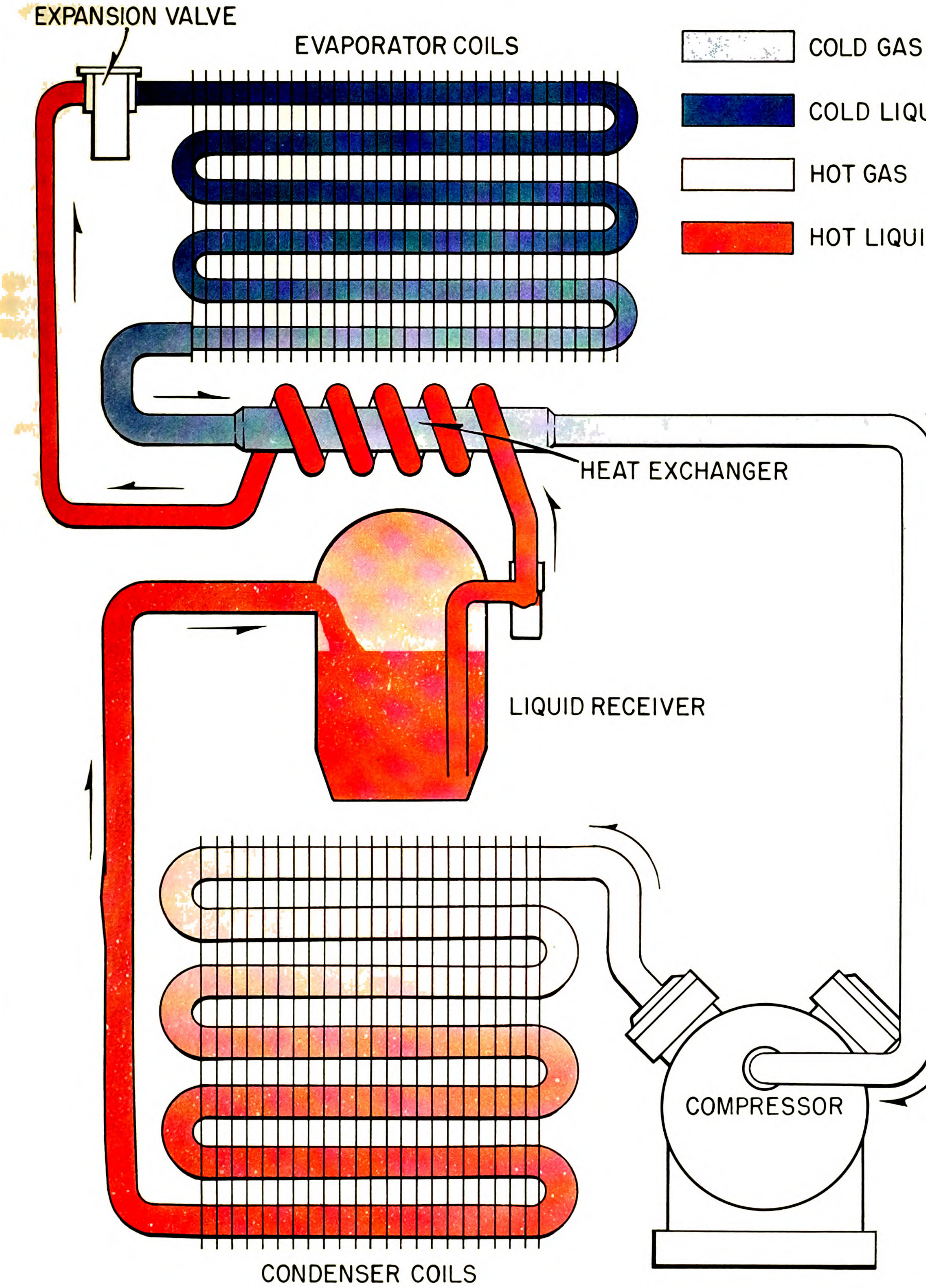


Figure 5-14.—Fundamental refrigerant cycle.

MAJOR COMPONENTS

Compressor

The compressor is used to remove (draw) gas from the evaporator and increase the pressure of the gas sufficiently for operation of the remainder of the system. Thus, by increasing the pressure of the gas, the temperature is raised above that of the medium (air or water) surrounding the condenser permitting heat to flow to the medium.

The size and type of compressor varies according to the installation and the requirements of the air-conditioning system. Compressors may be divided into three general groups: Reciprocating, rotary, and centrifugal. A second classification, as to type of compressor, is the open, semihermetic, and full-hermetic type. The function of the compressor is the same in all three types, but the mechanical means for accomplishing this task differs considerably.

OPEN RECIPROCATING TYPE.—This type of compressor is driven by an external means, which is normally belt-driven or direct-driven through coupling. One of the simplest ways of achieving high gas pressures is to draw a large quantity of gas into a cylinder through an intake or suction valve (fig. 5-15), by means of the partial vacuum produced by the downard movement of a piston. The piston is actuated by a crank arm or connecting rod attached to a crankshaft, which is rotated by the external driving force.

As the piston is moving down toward its lowest position, the cylinder is completely filled with low-pressure gas. As indicated in figure 5-15 (A) the suction (intake) valve opens when the pressure inside the cylinder is less than the pressure in the suction line leading to the cylinder. A common pressure at the suction valve is about 37 psig (pounds per square inch gage).

When the piston has reached the lowest point of its travel, it begins to move upward (fig. 5-15 (B)), and the intake (suction) valve closes. The intake valve closes when the pressure inside the cylinder becomes greater than that in the suction line.

The gas that has been compressed is delivered to the high-pressure (discharge) line through the discharge valve. As the piston moves upward the valve opens when it senses that the pressure inside the cylinder is higher than that in the high-pressure line. A common pressure at the discharge valve would be about 126 psig.

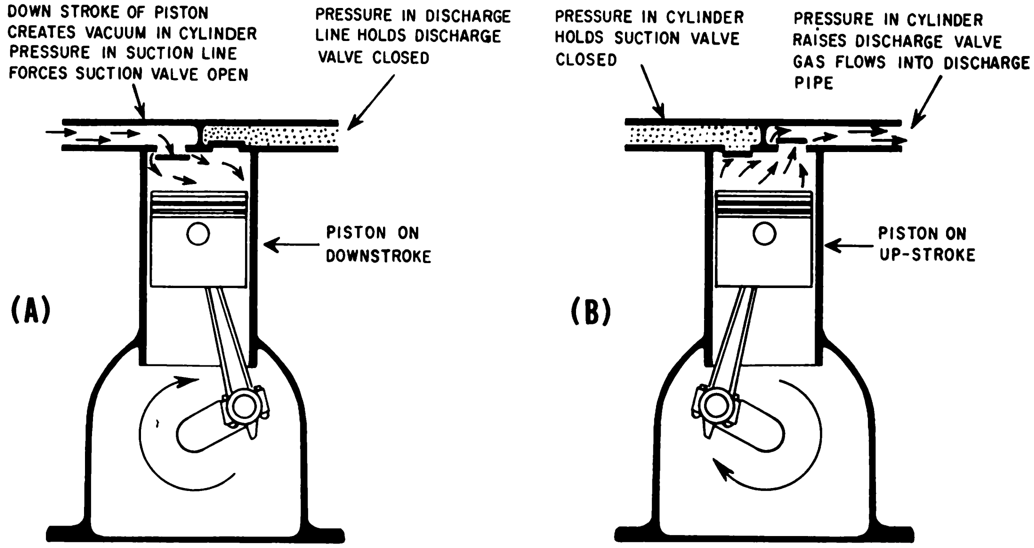

DOWN STROKE OF PISTON CREATES VACUUM IN CYLINDER PRESSURE IN SUCTION LINE FORCES SUCTION VALVE OPEN
PRESSURE IN DISCHARGE LINE HOLDS DISCHARGE VALVE CLOSED
PISTON ON DOWNSTROKE
(A)
PRESSURE IN CYLINDER HOLDS SUCTION VALVE CLOSED
PRESSURE IN CYLINDER RAISES DISCHARGE VALVE GAS FLOWS INTO DISCHARGE PIPE
PISTON ON UP-STROKE
(B)

Figure 5-15.—Operating cycle of a reciprocating compressor.

The valves, therefore, serve as one-way traffic-flow controllers; they permit the gas to flow in one direction only, and only when the pressures are of the correct amount.

The open type compressor has the advantage of supporting large systems. Also the power source can be any prime mover. The fact that the compressor is driven by an external source of power through a shaft creates operating disadvantages. Sealing around the shaft must be maintained to prevent gas, on the inside of the compressor body, from leaking outward into the atmosphere. The exposed belt drive or rotating couplings may prove dangerous to operating personnel. This type of compressor system requires considerable space for operating.

SEMIHERMETIC RECIPROCATING TYPE.—This type compressor has the compressor and direct drive motor housed within one casing or casting (fig. 5-16). The operation of the compressor is the same as the open type compressor. Both units are housed in a common enclosure which eliminates some of the disadvantages of the open type unit. The weight and space consumed are much less than that required by the open type compressor.

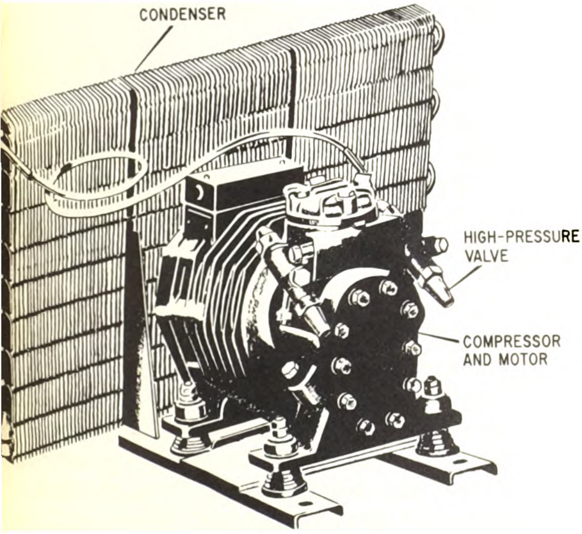


Figure 5-16.—Bolted type semihermetic compressor motor assembly.

FULL-HERMETIC RECIPROCATING T —The full-hermetic unit (fig. 5-17) is a pletely closed motor and compressor w into a pressed steel casing. This prevent type of field maintenance, and requires servicing be performed at very specia compressor overhaul centers, normally compressor manufacturer's plant. This compressor has all the advantages of s hermetic compressors plus additional w saving because of the much lighter pre steel casing.

ROTARY.—Another common type of pressor is the rotary type. This has distinct advantages as far as vibration moving parts are concerned. The mate used in construction are very similar to of the reciprocating pump, but its operati different. The major difference is tha pumping effect is produced by a rotary m rather than a reciprocating motion. F 5-18 illustrates an internal view of the sembly where the motor and compressor mounted in the same shell.

The operation of the stationary blade pressor is illustrated in figure 5-19. shaft rotates in a chamber so the eccen or offcentered disk, rubs constantly ag the outer wall of the chamber. Referri figure 5-19 the sequence of operation ca followed. With the chamber filled with (A) the eccentric starts to rotate. As eccentric rotates (B) gas imprisoned a of the eccentric is compressed and the

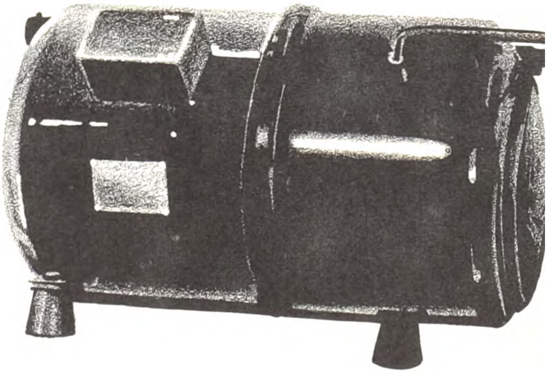


Figure 5-17.—Full-hermetically seale compressor motor assembly.

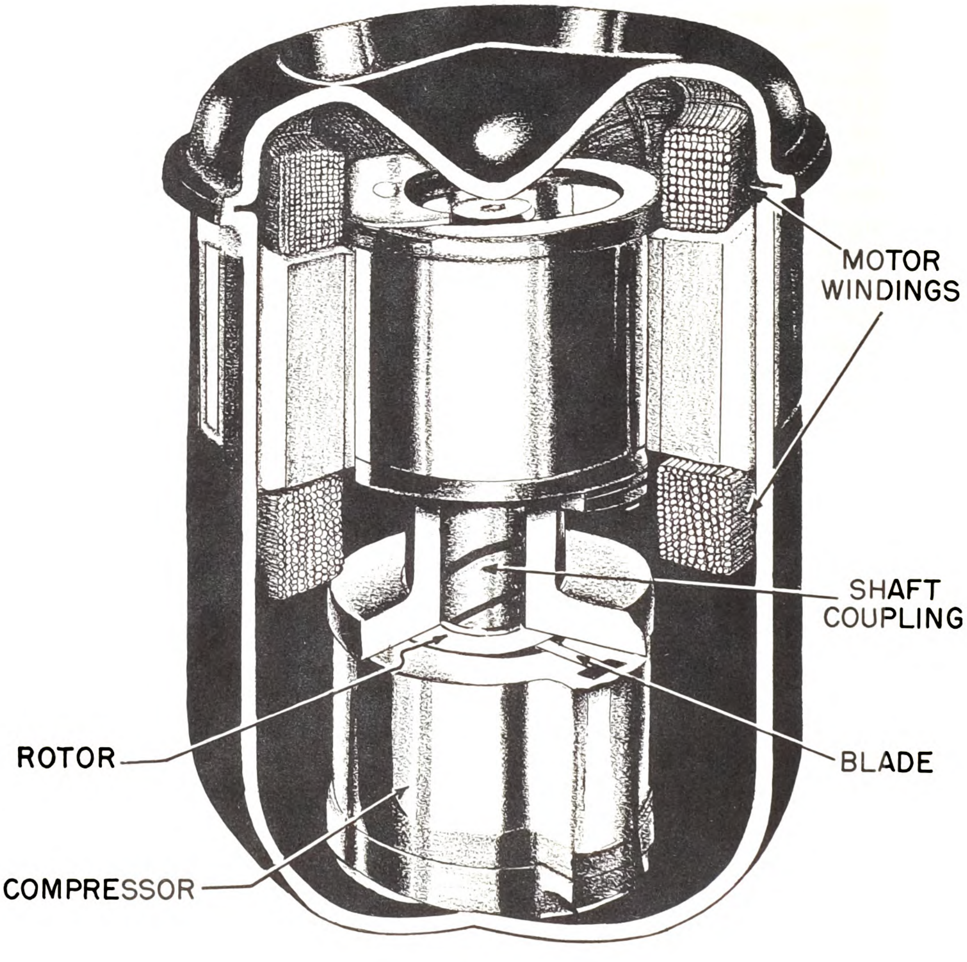


Figure 5-18.—Hermetic rotary compressor.

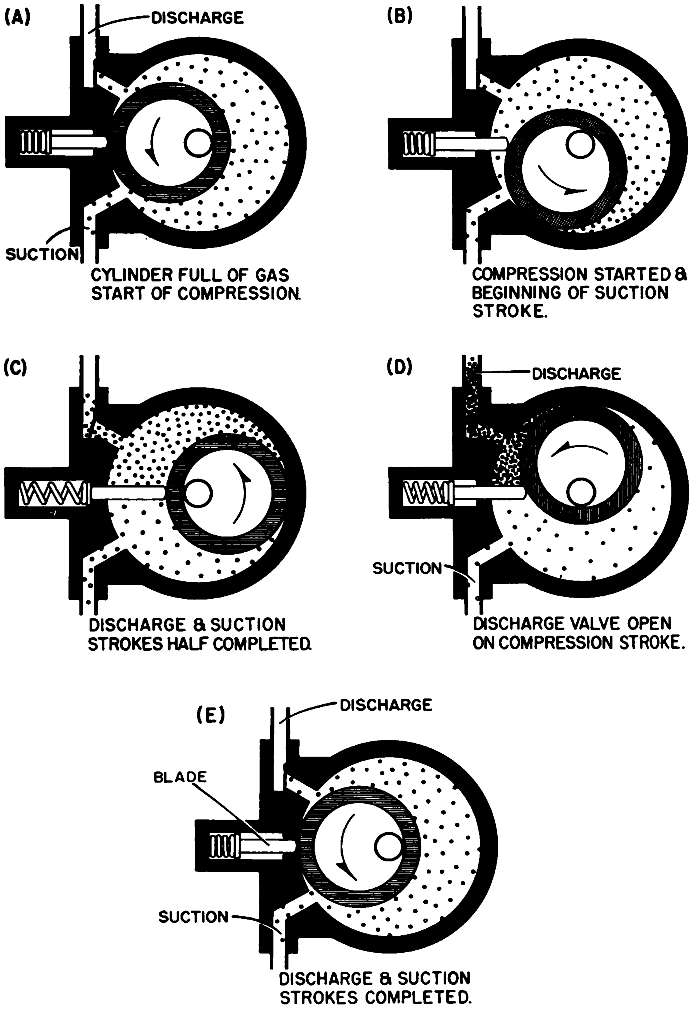
behind the eccentric sucks low-pressure gas into the chamber in preparation for the following cycle. As rotation continues ((C), (D), and (E)) the imprisoned gas is compressed into a smaller space, building up the pressure and temperature, and finally forcing the gas into the high-pressure side, or discharge side, of the system.

Another version of the rotary type compressor is the rotating blade. It differs from the compressor described above in that one or more pairs of blades are rotated in place of the eccentric. As these blades rotate they trap low-pressure gas from the suction line and force the gas into smaller and smaller spaces until at the discharge line the gas leaves as a high-pressure, high-temperature gas.

Compressor Motors

The driving mechanism or the source of power for compressor units is usually an electric motor. The type and size of the motor varies with the requirements of the particular installation. Two general types of motors used are the open and sealed motors. The open type, normally a capacitor motor (fig. 5-20), is a common type motor used in the air-conditioning field.

The capacitor type motor is normally a split-phase motor with a capacitor connected



(A) CYLINDER FULL OF GAS START OF COMPRESSION.

(B) COMPRESSION STARTED & BEGINNING OF SUCTION STROKE.

(C) DISCHARGE & SUCTION STROKES HALF COMPLETED.

(D) DISCHARGE VALVE OPEN ON COMPRESSION STROKE.

(E) DISCHARGE & SUCTION STROKES COMPLETED.

Figure 5-19.—Stationary blade rotary compressor.

in series or parallel with the windings to aid in the starting or running of the motor. In a capacitor-run motor the capacitor is used to aid the running winding, and is connected in parallel with the running winding. The capacitor-start motor derives its name from the use of a capacitor connected in series with the starting winding and aids the starting torque of the motor. Since the capacitor start is the most common motor used in air-conditioning equipment, it is discussed in greater detail.

In the capacitor-start motor, the capacitor, centrifugal switch, and starting winding are normally connected in series. The capacitor is in the housing mounted on top of the frame; the centrifugal switch is mounted in the rear end bell (right end, fig. 5-20); the starting winding is the smaller diameter wire and is usually placed on top of the running winding.

The centrifugal switch is in the closed position when the motor is not running. When voltage is applied to the motor, the capacitor-start motor acts as a two-phase motor when starting. The starting winding aided by the capacitor causes the rotor to rotate. When the rotor reaches 75 percent of its rated rpm the centrifugal switch is disconnected taking the capacitor and starting winding out of the circuit (fig. 5-21). The motor continues to run, but now as a single phase induction motor. More detailed information on motors may be found in Basic Electricity, NavPers 10086-A.

The troubles encountered in the capacitor type motor are few, and they deal mainly with the mechanical condition of the motor. There is a possibility that the centrifugal switch may become worn. Also an open or short circuit may occur in the capacitor or in the field

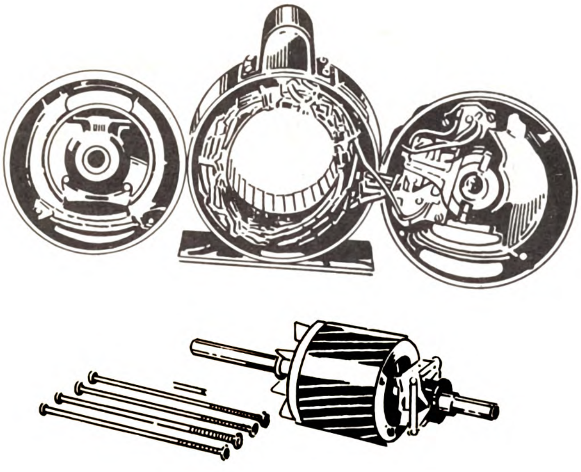


Figure 5-20.—A capacitor type motor.

windings. The mechanical troubles encountered are common to most types of motors. The most common of these are:

1. Worn bearings.
2. Excessive end play.
3. Excessive vibration.
4. Dirty.
5. Worn motor mounts.

Very frequent starting of the motor may result in overheating, which many times will cause the capacitor and/or the windings to fail. If the motor will not start, but simply has the characteristic hum, it is a sign that the capacitor or the centrifugal switch points have failed or the starting winding is open. It is a simple matter to substitute a good capacitor for the questioned one. If the motor still does not start, the trouble is possibly in the centrifugal switch or the starting winding. A continuity check should quickly determine the fault.

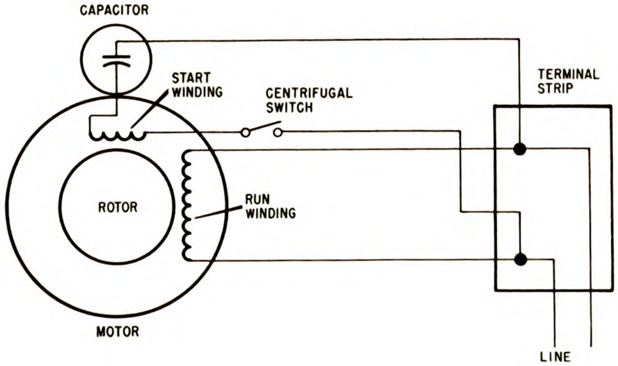


Figure 5-21.—A capacitor type motor schematic.

The basic operation of the hermetic type motor is essentially the same as the open type. There are some definite differences because of the motor being mounted in a sealed container (fig. 5-17) with the compressor. Brushes and/or open points cannot be used in the hermetic motor because the arcing would gradually disintegrate the refrigerant and the oil in the unit. Therefore, an external means must be used to disconnect and connect the various windings, and all torque must be developed by induction only. The electrical terminals which carry the circuit through the dome (container) must be electrically insulated from the dome; they must be also leak proof.

The higher starting torque required for those units which start under load necessitates the use of large conductors in the starting circuit. This required starting torque is usually obtained by using one of several electrical devices. Usually, manufacturers attempt to provide starting power equal to twice the running power. In other words, the attempt is to have a 1/6-horsepower motor produce one-third horsepower during starting. Likewise, various methods are used to disconnect the special starting devices after the motor has approached its full speed.

The two common types of motors used are the split-phase and capacitor start motor. As in the open type motor described above the split-phase motor has its starting and running windings mounted within the stator shell (fig. 5-22). In the split-phase motor these two windings are made into four coils each with the starting winding positioned at an actual 45° around the stator from the running winding. This positioning puts the starting winding 90 electrical degrees from the running windings. Smaller size wire is used in the starting winding. This smaller wire opposes the current and builds up its magnetic field slower than the running winding. This slower buildup causes a shift or side movement to one side in the electromagnetic field, thereby producing a twist or torque effect on the rotor which starts to rotate. The laminated rotor (fig. 5-20) is mechanically coupled to the rotary compressor (fig. 5-18).

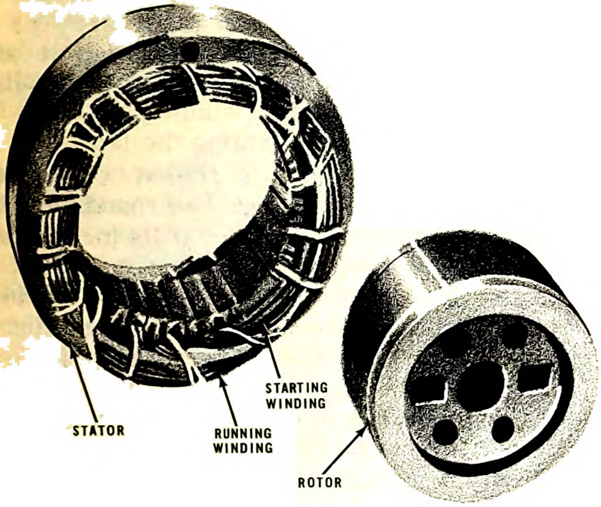


Figure 5-22.—A one-fourth hp. split-phase hermetic motor.

The servicing of hermetic motors may be divided into two major sections; external and internal servicing. Most of the hermetic motor troubles are external and may be traced to defective wiring or control devices. Occasionally a unit will not start, even though all the electrical tests indicate the unit is in good condition. This stuck condition may be caused by the unit standing idle for a long time, a particle of dirt, or an abnormal amount of liquid refrigerant is in the compressor. Three methods which may break loose the stuck unit are as follows:

1. Connect the power source directly to the motor connections, thus bypassing the control circuitry.
2. By using above normal voltage applied to the motor connections. This method should only be used for a short period of time.
3. By reversing the rotation of the unit, that is, making the motor run backward.

Motor-compressor systems have safety devices installed that open the electrical circuit if the motor draws too much current, if the motor overheats, and/or the compressor becomes too hot. Other sources of excessive heat occur from high exhaust fan temperatures, poor circulation, and friction.

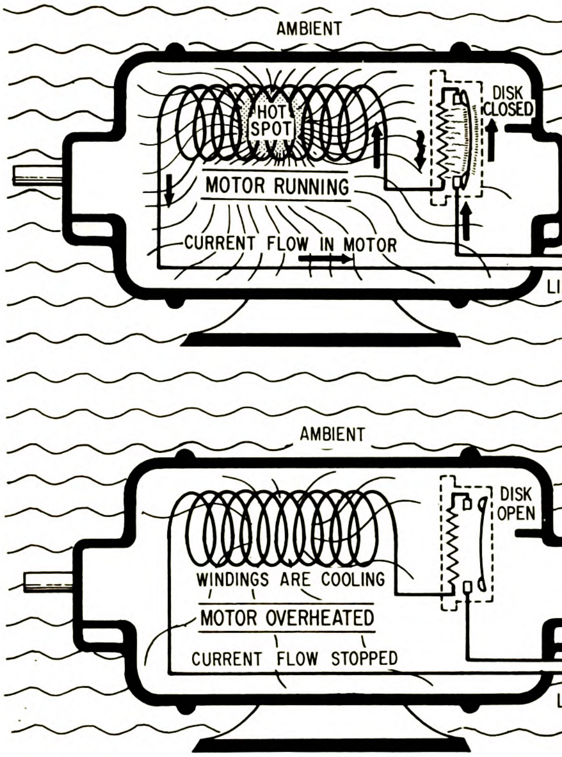


Figure 5-23.—Overload protection for a
open type motor.

One type of safety device used in open type motors uses a heating coil and a bimetal contact strip. (See fig. 5-23.) If excessive current flows through the heating coil it heats the bimetal strip. The bimetal strip b
when heated and opens the electrical ci
to the motor. The motor will not start a
until the bimetal cools sufficiently to a
complete the circuit. The bimetal strip
bend and open the circuit if heat from any so
is high enough to damage the motor or c
pressor.

For the sealed hermetic type motor-c
pressor system the bimetal safety devic
installed in the dome. (See fig. 5-24.) This
of bimetal disk is called a snap-action ther
disk. (See fig. 5-25.) When the bimetal
reaches a temperature that causes it to s
upward, the circuit is opened. Thus the bim
disk is temperature sensitive of heat f
the motor, the compressor, and the cur
drawn by the motor.

Condensers

The function of the condenser coil (fig. 5
in a refrigeration cycle is to convert the

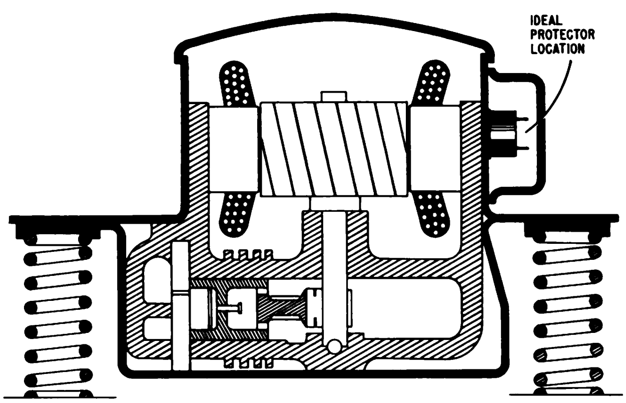


Figure 5-24.—Overload protection for a sealed hermetic motor-compressor.

refrigerant gas discharged from the compressor into a liquid state before it is ready for use again in the evaporator. The condenser accomplishes this by removing heat from the hot gas to cause it to condense at the pressure existing in the high pressure side of the system. The heat-dispelling effect of the condenser must be equivalent to the sum of the following:

1. The amount of heat absorbed by the refrigerant in the evaporator.
2. The amount of heat caused by the friction of the gases going through the suction (low pressure) line.
3. The amount of heat absorbed by the gases while increasing in pressure by the compressor.

There are two general types of condensers, the air-cooled and the water-cooled condenser. The condenser (fig. 5-16) is many sections of tubing connected as a continuous pipe and mounted within a block of thin wafer-like metallic fins.

AIR-COOLED.—The air-cooled condenser (fig. 5-26) utilizes ambient (surrounding) air, and by means of fans pushes or pulls (preferably pulls) the air through the condenser block of pipes and fins. Refrigerant cooling is obtained by adequate condenser surface and maximum air circulation over the outside condenser coil surfaces. Maximum condenser surface is obtained by closely spaced fins on the coils. The coil and fan arrangement is similar to an automobile radiator.

The air-cooled condenser is the type of condenser with which the TD will normally be concerned. It is utilized in window type installations and in mobile trainer units. The maintenance required is relatively minor and consists mainly of keeping the coil and fins clear from dust and dirt. This cleaning can best be done with a vacuum cleaner and soft-haired brush.

WATER-COOLED.—Water-cooled condensers (fig. 5-27) utilize water flowing inside a pipe with the refrigerant gas flowing outside the pipe. One version of this type cooling is called the shell-and-coil in which the refrigerant gas is fed into a tank in which coils of pipe circulate the water in and out of the tank. Another version is called the double-tube in which a smaller tube is spaced inside another tube. The water flows through the inside tube

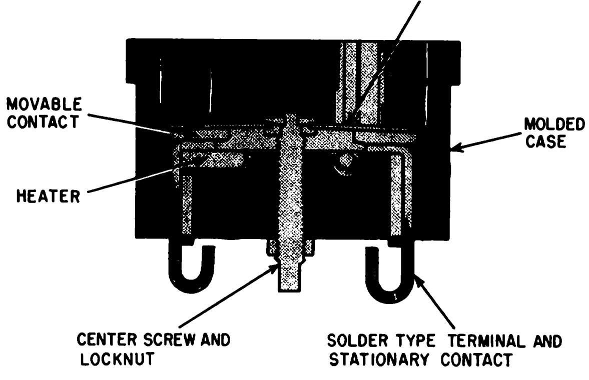


Figure 5-25.—A bimetal disk protector.

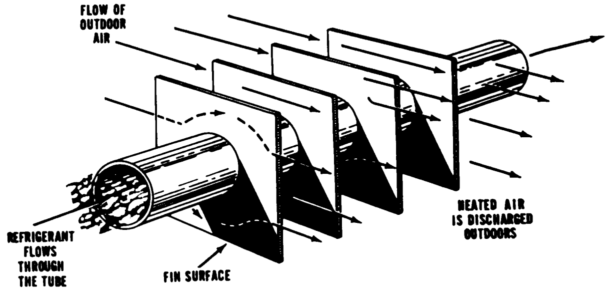

FLOW OF OUTDOOR AIR
HEATED AIR IS DISCHARGED OUTDOORS
REFRIGERANT FLOWS THROUGH THE TUBE
FIN SURFACE

Figure 5-26.—Air-cooled condenser.

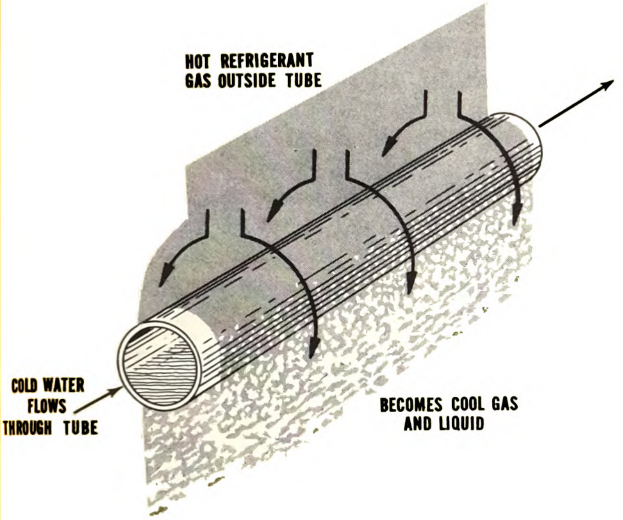

HOT REFRIGERANT GAS OUTSIDE TUBE
COLD WATER FLOWS THROUGH TUBE
BECOMES COOL GAS AND LIQUID

Figure 5-27.—Water-cooled condenser.

while the refrigerant gas flows through the space between the inner and outer tubes. Another arrangement is the shell-and-tube which consists of a tank with water pipes arranged inside. The water pipes are straight, not coiled as in the shell-and-coil arrangement.

The water-cooled condenser is commonly used in air-conditioning systems installed in trainer buildings. Water is circulated through the condenser by an auxiliary water supply. The water temperature should be as cool as possible for best results. If an unlimited water supply is available, the circulated water is passed off into the drainage system after it has been used. Under normal conditions the water is restricted hence a system must be employed to reuse the water.

A water conservation unit such as a cooling tower may be employed. The warm circulated water is pumped outside the building and raised to the top of the tower (fig. 5-28) where water sprayers release the water to fall down through the tower into the water collecting tank. As the water drops in spray form outside air or forced air passing through the tower causes evaporation of some of the water droplets. The evaporation is similar to the evaporation of sweat from skin; it results in a cooling action. In this case, the evaporation of part of the water causes the remainder of the water to be cooled to some extent. The

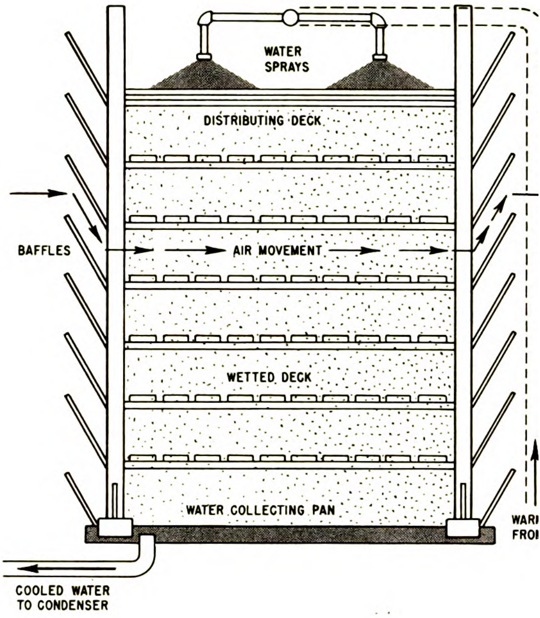


Figure 5-28.—Cooling tower.

cooled water is collected at the bottom tower and returned by pipes to the cond The amount of water that evaporates duri cooling process is automatically added system.

The water-cooled condenser type syste quires continuing maintenance. The wate must be kept clean, free from leaks, and be drained for winter weather. The c tower must be kept free of leaves, and dirt. Pumps, spray nozzles, and float must be kept cleaned and oiled.

Receiver

The receiver (fig. 5-14) is a storag for liquid refrigerant. The high pressure from the condenser enters the receive at a coupling near the top. The dep liquid leaves through a coupling locat the upper portion of the tank. This mo is placed here for convenience becau the outlet of the receiver there should service valve, commonly called the rec or king valve. It is essential that th leading away from the receiver contai liquid refrigerant. A "quill" is connecte ternally to the receiver valve which dips to the bottom of the receiver tank (fig. 5-14), assuring that liquid refrigerant enters the quill and leaves the receiver.

Expansion Valve

The function of an expansion valve is to change the high-pressure liquid to a low-pressure liquid. The output of the expansion valve is automatically controlled to insure that the correct quantity of refrigerant to keep the cooling unit operating at maximum efficiency and without overloading the compressor is passed. (See fig. 5-14.) The action of the valve is very similar to a spray nozzle, and while the compressor is running, the liquid refrigerant is sprayed into the cooling unit tubing.

Many different forms of expansion valves are found in air-conditioning equipment. Some of them operate when a temperature change occurs in the refrigerant flowing past the valve, an others operate when a pressure change occurs. In principle, regardless of the complications of any particular device, the valve is as simple as the illustration in figure 5-29. When a gas or liquid is squeezed through a small opening, and then allowed to expand into a larger chamber, the pressure decreases.

A modification of the valve orifice, that has come into extensive use in small refrigeration machinery, is the capillary tube. Essentially, the orifice (fig. 5-29) is replaced by a long tube of extremely small diameter as indicated in figure 5-30. The main advantage of the capillary tube is that no moving parts are required. Each capillary tube must be specially designed to fit a particular size unit. It is essential that clean refrigerant be used that does not clog the tube (which may be as small as 0.04 inch in diameter and several feet long).

The pressure method of operating an expansion valve is illustrated in figure 5-31. The figure shows a flexible bellows B1 connected to the needle of a needle valve and having the cooling unit (evaporator) pressure P2, pushing up on the inside, and atmospheric or confined gas pressure P1 pushing downward. The spring force F1 tends to open the valve, while F2 tends to close the valve. It can be seen that as the pressure in the cooling coil (low-pressure line P2) decreases, the

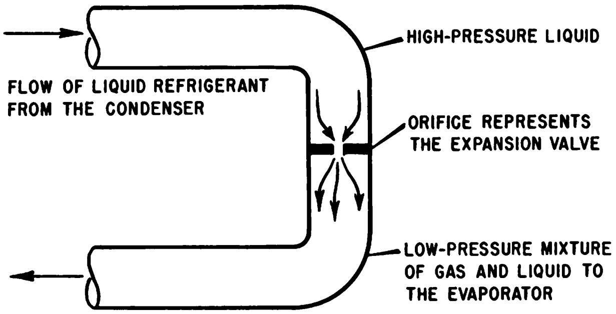

HIGH-PRESSURE LIQUID
FLOW OF LIQUID REFRIGERANT FROM THE CONDENSER
ORIFICE REPRESENTS THE EXPANSION VALVE
LOW-PRESSURE MIXTURE OF GAS AND LIQUID TO THE EVAPORATOR

Figure 5-29.—Expansion valve principle.

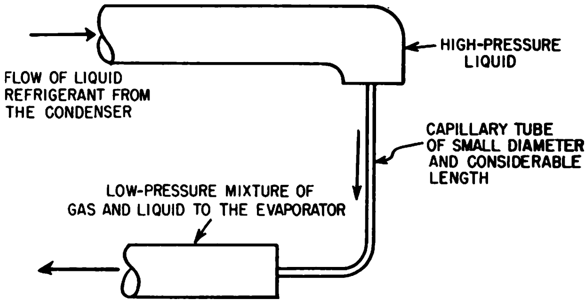

HIGH-PRESSURE LIQUID
FLOW OF LIQUID REFRIGERANT FROM THE CONDENSER
CAPILLARY TUBE OF SMALL DIAMETER AND CONSIDERABLE LENGTH
LOW-PRESSURE MIXTURE OF GAS AND LIQUID TO THE EVAPORATOR

Figure 5-30.—Capillary tube as an expansion valve.

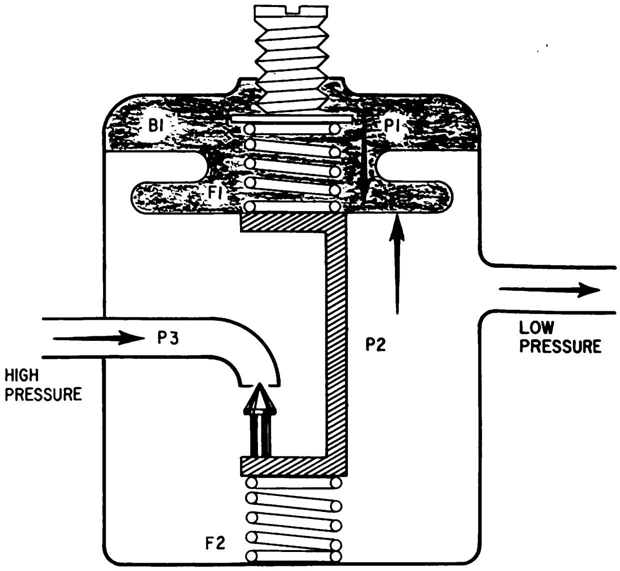


Figure 5-31.—Pressure expansion valve.

differences in pressures forces the bellows down toward the valve body. The valve body is connected to the needle and opens the needle valve allowing some liquid refrigerant to spray into the low-pressure line and into the cooling coil (evaporator). The opening of the needle valve allows pressure P1 to push the bellows B1 upward until the needle valve is again seated which shuts off the high-pressure gas P3.

The opening of the expansion valve occurs when the compressor is running and reducing the pressure. The expansion valve prevents flooding the low-pressure side when the compressor is running. As soon as the evaporating refrigerant vapor reaches the end of the cooling unit (evaporator) tubing, the motor control safety valve becomes too cold and stops the motor. This allows the low-pressure line to build up sufficient pressure (P2 of fig. 5-31) to close the needle valve in the expansion valve.

The pressure type expansion valve is adjustable to permit the opening of the needle valve over a varying range of pressures. Valve adjustments must be made for varying altitudes as their operation is influenced by atmospheric pressure. Also different refrigerants require different settings. The valves are made in a variety of designs and adjustment procedures for any one particular type are normally furnished by the manufacturer and should be closely followed by the maintenance man.

The thermostatic expansion valve is an improved type of expansion valve, having a thermostatic or temperature sensitive bulb mounted on the evaporator tubing (fig. 5-32).

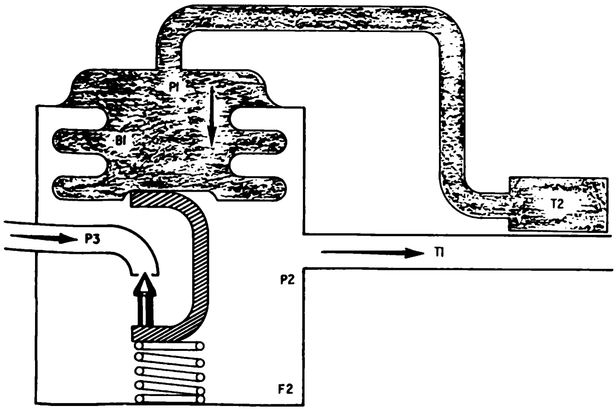


Figure 5-32.—Thermostatic expansion valve principles.

The bulb T2 is connected into the bellow o diaphragm B1 by very small tubing. This voi is filled with the same refrigerant as used i the compressor system. As the bulb T2 becomes warm, the pressure of its refrigerar expands, and builds up pressure in the diaphragr B1 power element. The bellows then expanc forcing open the expansion valve needle, an liquid refrigerant (P3) flows into the coolin coil (evaporator) line T1.

After the cooling coil (evaporator) is cooled the suction line to the compressor begins t cool. The bulb T2 also cools, pressure withi it decreases, and the fluid within it contracts This causes a contraction of the bellows B1 which in turn causes the diaphragm to clos the valve needle.

The actual parts for this type of expansio valve are illustrated in figure 5-33. The principl of operation is essentially the same as th basic illustration (fig. 5-32). The assembl functions to keep the cooling coil (evaporator supplied with refrigerant which is differen from the pressure automatic expansion valv shown in figure 5-31, which maintains a specified low-pressure. It does not enter at al into the regulation of pressure on the low-pressure side of the system because the compressor establishes its own pressure upon th refrigerant.

Evaporator (Cooling Coil)

The evaporator (fig. 5-34) consists of a coi of tubing mounted in a block of thin metalli fins. The refrigerant travels from the expansio valve in the form of liquid and gas to the coolin coil (evaporator). The evaporator coil is coole by this change of state of the refrigerant. Th air to be cooled is then directed over the coi and cooling of the air is accomplished.

As the warm air is passed over the outside of the evaporator, heat is transferre from the air to the refrigerant through th metal walls and fins of the coil. Heat i transmitted from the warm air to the fi surfaces, to the circular pipe, and then to th refrigerant. The heat applied to the outside o the tube causes the refrigerant to boil. As a result of boiling, the liquid refrigerant change into a gas, but remains at the same low pressure This gas is eventually drawn back to the suctio side of the compressor. Also, as the warm humi air comes into contact with the cold metal moisture in the air is condensed on the coo coil and drips down off the evaporator.

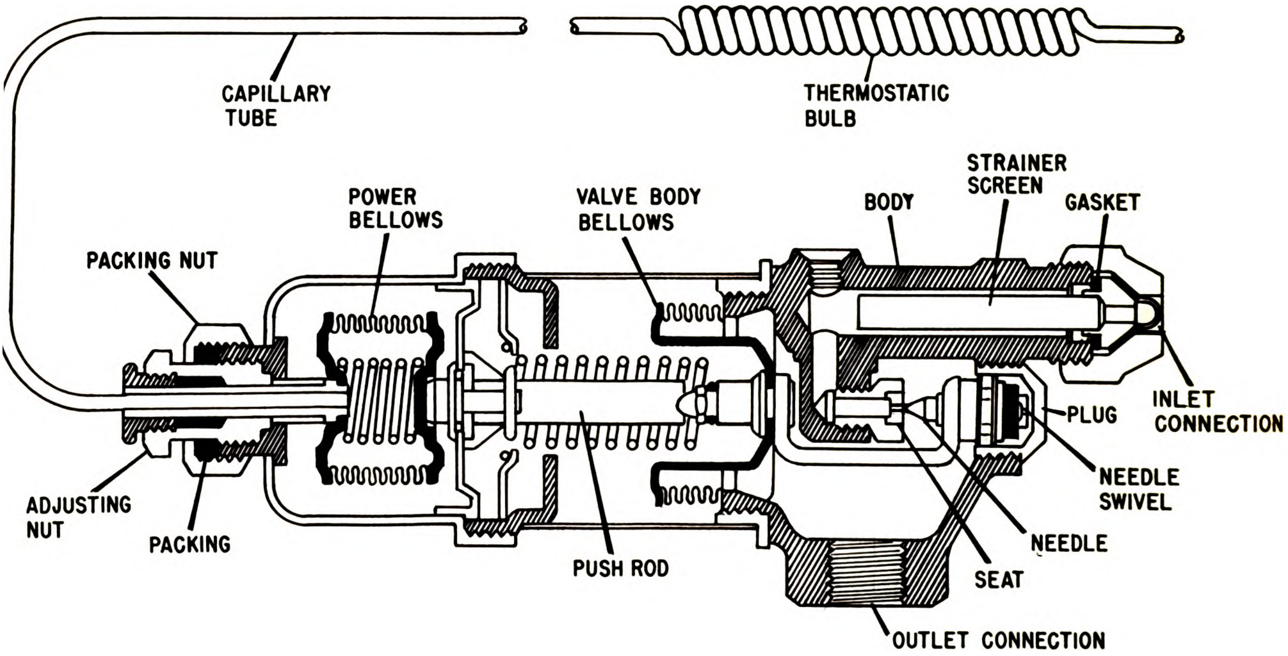


Figure 5-33.—Thermostatic expansion valve.

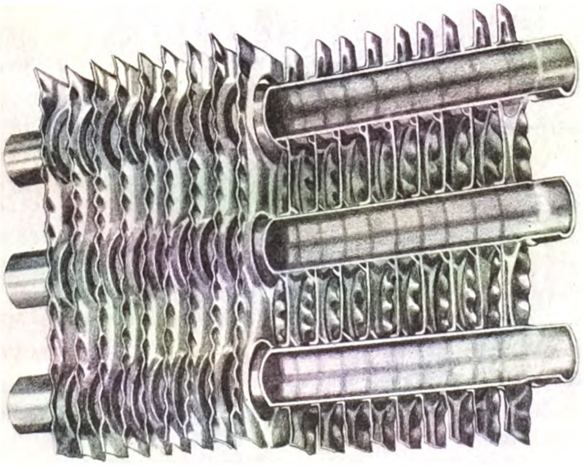


Figure 5-34.—Evaporator.

REFRIGERATION ACCESSORIES

There are various accessories that can be added to the major components to provide either simplified maintenance or increased efficiency without changing the function of the refrigeration system.

SERVICE VALVES

The service valves, referred to as the head and suction valves, are utilized for maintenance and charging the system. The head valve is mounted on the high-pressure port of the compressor and the suction valve is mounted on the low-pressure side. The construction of the valves and their method of operation are identical. (See fig. 5-35.) However, they differ in size, use, and placement.

The valve cap for a compressor service valve contains a gasket which forms a refrigerant tight fit between valve cap and valve body. The valve cap and gasket must be removed to position the valve plunger. The valve plunger is normally positioned in the forward seated, back seated, or cracked position. Always use the wrenches provided with the air conditioner for adjusting the service valves.

To forward seat a service valve (fig. 5-35), turn the valve stem clockwise as far as it will go. This puts the plunger to the left and tight against the forward seat which stops gas flow at this point.

To back seat a service valve (fig. 5-35), turn the valve stem counterclockwise as far as it will go. The valve plunger is now to the

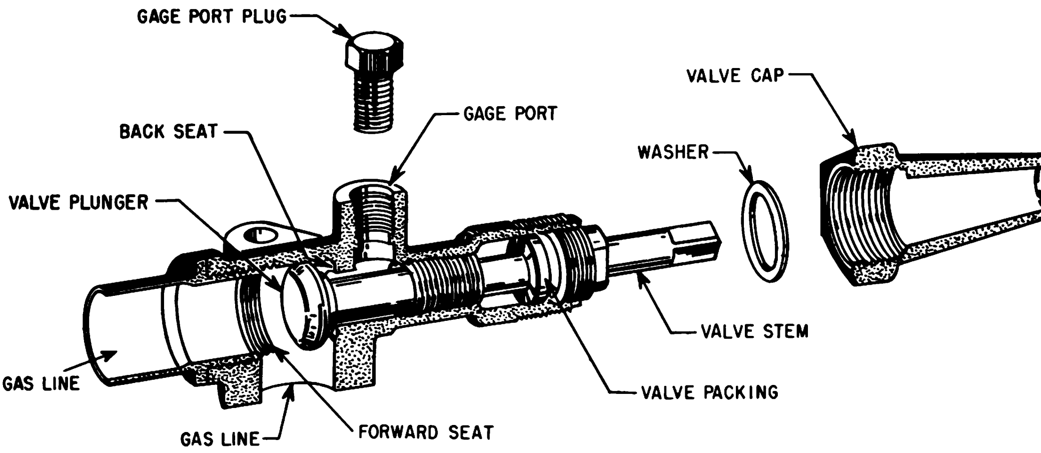


Figure 5-35.—Service valve.

right and tight against the back seat. The gasline is now completely open.

To crack a service valve (fig. 5-35), first back seat and then turn the valve stem one-fourth turn clockwise. This moves the valve plunger slightly to the left which allows gas to flow into the gage port.

To install a pressure gage in a service valve, back seat and remove the gage port plug; then insert the gage and crack the service valve so the gage will read.

Never operate the compressor with the head service valve forward seated. This condition blocks the output of the compressor allowing the pressure of the compressor to build up sufficiently to become dangerous to personnel and will damage the compressor.

VIBRATION ELIMINATORS

Vibration eliminators are employed to absorb and remove any inherent vibration in copper tubing caused by floating components. The vibration or movement is absorbed in the eliminator due to its construction. It is constructed of an accordion-like, phosphorous bronze tube with copper fittings at each end of the eliminator to facilitate joining with the system tubing. The name for the accordion-like material is called convolutions.

On some air-conditioning systems, such as the one used in the 2F23 training device, a simple loop is made in the refrigerant tubing itself. The loop allows the vibrations to be absorbed in the extended length of tubing.

LIQUID LINE SIGHT GLASS

The sight glass is a visual indicat for maintenance purposes to visually de the condition of the refrigerant ente thermal expansion valve. The sight glas be located on the inlet side and as clos thermal expansion valve as possib appearance of the refrigerant passing the sight glass should be clear. If the should indicate a cloudy or milky app this indicates that the level of refrig low. The milky appearance is caused Freon gas bubbles passing through the mixed with the liquid refrigerant.

RECEIVER VALVE

The receiver valve, referred to as valve, is located on the output side of the tank. This valve is used when it is ne to trap the refrigerant in the recei condenser lines.

HEAT EXCHANGER

The heat exchanger (fig. 5-14) is e to obtain better efficiency. Hot liquid f receiver, which is to be cooled in the eva transfers heat to the cool suction gas on its way back to the compressor. T exchanger is constructed to carry the the smaller of the two tubes which is m cally connected to the large tube carr cool suction gas. The two tubes are co into the system so that the inputs and are in the same direction.

DRIER STRAINER

The drier strainer, also called a catchall, is employed to remove any foreign matter or water from the refrigerant gas. Foreign material could clog small openings and water could freeze in the expansion valve. It is located between the expansion valve and heat exchanger. The refrigerant passes through a filter cloth where foreign material is trapped, and then through a porous material where water is absorbed from the system.

When maintaining an air-conditioning system if the drier strainer should feel cooler than the liquid line entering the drier, it is an indication that the unit should be replaced. The connecting ports of the filter are marked in and out to insure proper connection to the system.

AIR FILTERS

Cleanliness within any confined space is important. Two types of filters commonly used in the removal of dust, bacteria, and odor are the dry filter and viscous filter.

The dry filter which removes the dirt by passing the air through small openings in felt, spun glass, or paper screens is generally of a disposable type. When this filter becomes loaded with dirt, it is discarded.

The viscous filter depends on the dirt adhering to a surface covered with a viscous fluid or oil and is generally of the permanent type filter. When this type filter is dirty, it can be reused only if it is retreated with a viscous fluid or oil. The cleaning process for this type filter is as follows:

1. Gently tap the filter to remove loose dirt.
2. Wash with hot water applied to the dirty side of the filter and flush out dirt and old adhesive.
3. Shake off excess water and allow the filter to dry.
4. After the filter is dry, it should be treated with a commercial filter adhesive.

The advantage of using a commercial preparation for treating the filter is the active germicidal and fungicidal ingredients which are contained in the fluid. If a commercial preparation is not available, a very light oil can be substituted. In applying the filter adhesive, a liberal coating should be placed over the entire surface of the filter, but care should be taken to avoid excess.

The manufacturer's operation and maintenance manual should be consulted and followed when adjusting and maintaining a particular air-conditioning system. When installing controls which employ capillary tubes, avoid making sharp bends or kinks in the tubing. Coil and secure excess capillary tubing to avoid vibration. Allow some slack in the tubing to avoid vibration which can cause tubing to break. Do not allow tubing to rub against metal surfaces where vibration will cause breakage.

Proper maintenance of filters is a very important task for the efficient operation of any air-conditioning system. As can be realized, when the cycle of operation is reviewed, the passage of air is essential for the successful operation of any air-conditioning system. When performing preventive maintenance checks, always inspect the filter with special attention to the following:

1. Check the condition of the disposable filters, looking for thin spots and holes as well as dirt. If spots or holes are present, the filter should be replaced.
2. If dirt has accumulated on any filter it should be cleaned off, treated in the case of permanent filters, and reinstalled. A clogged filter reduces airflow and is a source of dirt.
3. If over a prolonged period of inspections, very little dirt accumulates on a permanent viscous filter then the adhesive coating should be carefully checked. This condition probably does not indicate a clean condition, but rather the fact that the adhesive coating is not doing its job. The filter should be removed, cleaned, and recoated.

CONTROLS

Air-conditioning equipment utilizes two distinct types of controls. These controls may be classified as the operating and safety controls. The operating controls maintain the desired conditions, while the safety controls are used to prevent damage to the equipment.

OPERATING CONTROLS

The operating controls of an air-conditioning system may be as simple as turning on and off a heater and turning on and off the compressor to control cooling. Some systems provide functions other than cooling. Interlocking controls are used in conjunction with humidistats to control humidity along with temperature.

It is possible to increase the complexity of the control system to incorporate almost any type of automatic control desired. The operating control system for each particular system is usually presented verbally and schematically in the applicable operation and maintenance handbook.

Thermostat

A thermostat is a device for the automatic regulation of temperature utilizing the expansion and contraction of metals or gases caused by the change of temperature. The single pole thermostat controls a cooling system by turning it on and off at adjustable temperatures.

The two-position heating-cooling thermostat controls the operation of the air-conditioning system by selecting heating or cooling. The heating function of air conditioning is discussed in chapter 6 of this course. A simple diagram is illustrated by figure 5-36. All of the components are mounted on a bakelite base. When the bimetal element cools, it contracts and moves away from contract R toward contact B. When the bimetal element is heated, it expands and moves toward contact R and away from contact B. When the bimetal element moves toward either contact the detents, which are two small magnets, attracts the element to the contact, rapidly closing the control circui This reduces arcing and burning of the conta points. The adjustment lever is set to the desir room temperature. If a warmer temperatu is desired, the adjustment lever is rotated the right. The bimetal element in turn mov closer toward contact B. The element wou now have less distance to travel in order turn the heating system on. When the desir temperature is reached, the bimetal eleme expands and moves away from contact B, ope ing the heater control circuit.

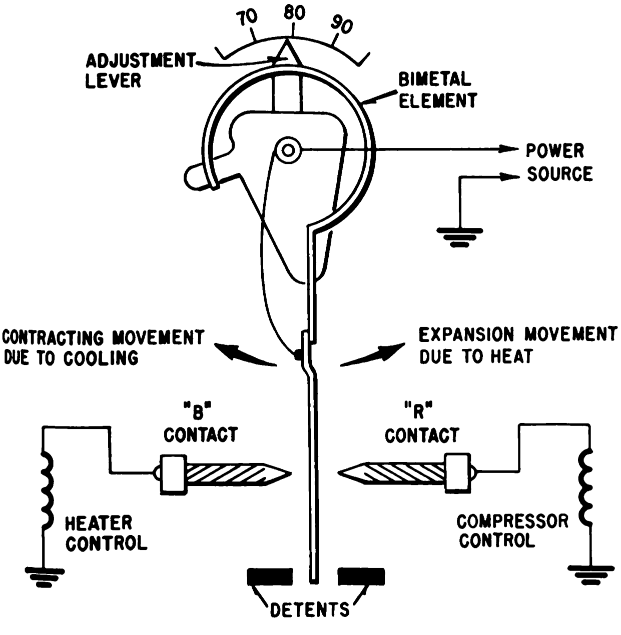


Figure 5-36.—Two-pole heating-cooling thermostat.

Common commercial thermostats are sens tive to ± 2° F. The location of the thermost is very important. It should be located whe it is exposed to unrestricted, natural air ci culation, and for average conditions of t conditioned space. It should not be locat near isolated sources of heat or cold; such lamps, motors, sunlamps, concealed pipes ducts within the wall; which may affect t control point temperature.

Humidistat

The humidistat is designed to control eith humidifying (adding moisture) or dehumidifyi (removing moisture) equipment, or to contr both with one instrument.

The operating element is composed of a proximately 150 strands of human hair (fig. 5-3 (thin strips of balsa wood is used in some unit carefully selected and specially treated. Th element is sufficiently sensitive that the slighte change in humidity will cause the control function. The control unit is mounted vertical so that dust and foreign matter does not adhe to the strands of the hair.

The principle of operation is illustrat in figure 5-38. The sensitive element, huma hair or wood, stretches when the ambient a humidity increases and contracts as humidi decreases. With the amount of tension on t sensitive element remaining constant, it c be seen that by rotating the humidity selecti control levers A (fig. 5-38) and B will mov Rotating the humidity selection control clockwise, indicated by the arrow, moves levers and B counterclockwise around pivots G and As lever B rotates counterclockwise it push the top of lever H moving contact E towa contact C. This action sets the condition f automatic operation. This adjustment is he constant by the spring attached to lever B. small amount of additional dryness and contact

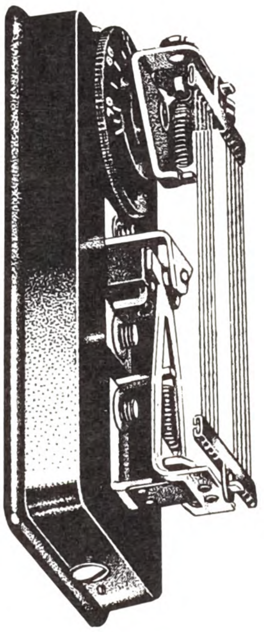


Figure 5-37.—Humidistat.

C and E will close, completing the control circuit to add moisture.

If the moisture content of the ambient air increases, the sensitive element will stretch (fig. 5-38). The lever H will rotate counterclockwise which moves contact E toward contact D. When contacts E and D close, the dehumidifying control circuit activates to reduce the moisture content in the spaces.

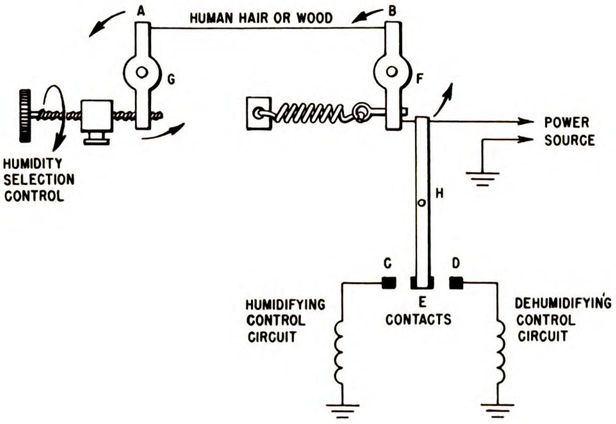

A
HUMAN HAIR OR WOOD
B
G
F
POWER SOURCE
HUMIDITY SELECTION CONTROL
H
C
D
HUMIDIFYING CONTROL CIRCUIT
E CONTACTS
DEHUMIDIFYING CONTROL CIRCUIT

Figure 5-38.—Humidistat principles.

Condenser Fan Control

A condenser fan control is a device for the automatic control of condenser fans utilizing the high side system pressure of the compressor to turn the condenser fans on and off at predetermined pressure settings. When the fan is off, the refrigerant in the compressor is hotter and there is a greater volume of gas, consequently the compressor head pressure increases. High-pressure gas is metered to the bellows in the control unit (fig. 5-39) through a capillary tube. As the head pressure increases, the bellows expands until the switch contacts close. When the contacts close, the circuit to the condenser fan is completed.

With the condenser fan in operation, the compressed gas is cooled by ambient air blowing across the condenser. This action causes the gas to condense to a liquid, and the head pressure is reduced. When the pressure drops below the specified setting, the bellows contract, opening the switch and stops the fan.

Circuit Control

The control of the various circuits of a system may vary from simple toggle switches to remote controlled contactor relays. These switches may be used for actuating fans, lights, motors, or for the checking of various circuits while troubleshooting a defective system. Switches used for maintenance work are called service switches.

A contactor is a type of electrical relay which is used in complex systems where various modes of air conditioning are controlled for more than one refrigeration system. The contactor (fig. 5-40) has many separate relays mounted on one block. The size of the contacts vary in size according to the current load of

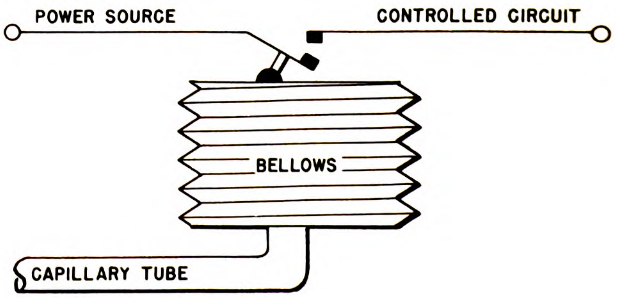
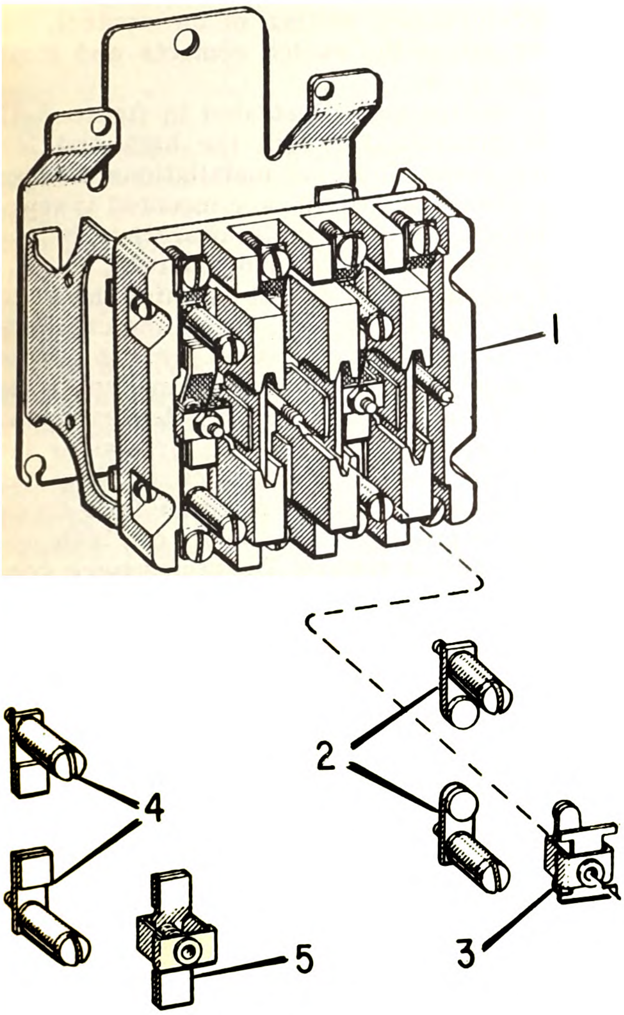


Figure 5-39.—Condenser fan control.



1. Mounting block.
2. Medium duty stationary contacts.
3. Medium duty movable contacts.
4. Heavy duty stationary contacts.
5. Heavy duty movable contacts.

Figure 5-40.—Contactor relay.

the circuit that is controlled. The movable contacts are moved individually or as a complete group according to the type of contactor. This allows the control of a single circuit or many circuits simultaneously.

SAFETY CONTROLS

Sufficient safety devices are installed in air-conditioning systems to prevent body injury to operating personnel, damage to the system's equipments, or to the equipment and spaces receiving the conditioned air.

Fusible Plug

The fusible plug is provided tc excessive buildup of refrigerant pressu the confined area of the equipment. frigerants commonly used today wi accordance with the normal liquid/g whereby increasing temperatures ca creasing pressures. Should the air-co equipment be in close proximity to positive method of releasing gas and li in the refrigeration system must be pr prevent the build-up of pressure withi tem. The fusible plug is normally loca inlet connection of the receiver tank. cessive external heat is present, due other similar causes, the plug melts all refrigerant gas to escape from the sys reduction of gas pressure prevents rupture or explosion of the equipment.

Overload Switches

An example of the overload safe was described for the compressor and sor motor. When failures occur w equipment, the overload switch opens cuits supplying power to the equipment

Thermal Cutout

This safety control is used in ins that provide electric heaters for th of the conditioned spaces. The therm has an adjustment whereby a prede temperature can be set. If the ten rises above the setting, the therm opens the circuit to the electric heat safety device protects the units loca the heaters from abnormally high tempe

High- and Low-Pressure Cutouts

The high- and low-pressure cutout are incorporated in the refrigeration control the operation of the compres pressure control prevents the dischar sure of the compressor from building a reasonable limit. This control co electric switch and a bellows (fig. 5-3 through appropriate linkage, opens an the motor circuit of the compressor.

The basic operation is similar shown in figure 5-39 with the addit method for adjusting the desired cuto sures. (See fig. 5-41.) A capillary tu mits the pressure from the high si refrigeration system to the bellows

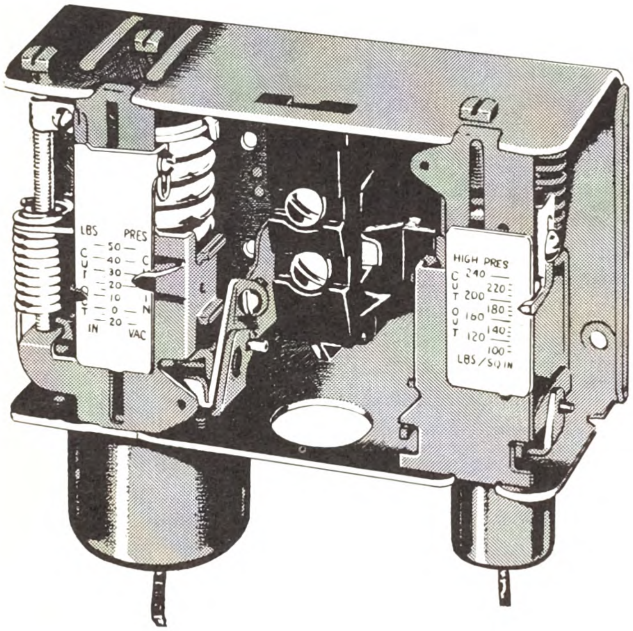


Figure 5-41.—High-and low-pressure cutout.

the compressor head pressure increase above the predetermined setting of the control, the pressure opens the switch contacts and stops the compressor.

The control unit illustrated in figure 5-41 contains controls for both the high and low pressure gases. In some installations the high and low pressure controls are mounted in separate units; however, their operation is essentially the same as described herein.

The low-pressure cutout operates the same as the high-pressure unit, except the capillary tube transmits the pressure present in the suction side of the refrigeration system to the bellows. If the suction pressure decreases too low (at or near atmospheric pressure) the bellows will operate the switch to stop the compressor. If the suction pressure falls below atmospheric pressure, outside air can leak into the refrigeration system. The atmosphere contains water vapor, and if any portion of the refrigeration system is below atmospheric pressure and a leak exists in any portion of the system, air entering the system through a leak would be very detrimental to the interior workings of the system.

CHAPTER 6

AIR-CONDITIONING SYSTEMS

The air-conditioning systems that the TD may encounter vary from the common window unit to multistage mechanical compressor systems. The equipments presented in this chapter provide examples of the types of systems in use. Even though air-conditioning systems may vary between trainers, their operation is based on the same principles.

VENTILATING SYSTEMS

Mechanical ventilating systems are installed to supply fresh air where natural ventilation is insufficient. Primarily they are utilized to remove heat and vapors, but they may also be used to collect and remove dust from training spaces. The system is used to circulate air to increase the comfort of trainees and in some cases to aid in the efficient operation of training equipment.

The circulating fan is equipment for stirring the air in an occupied space. The cooling effect that the occupant obtains comes from the air motion over him. This method of cooling was discussed in the previous chapter.

The exhaust fan or blower pulls or pushes the air across the space and discharges the air to the outside. This action removes heat, vapors, and dust from the training space.

ADDITIONAL PROCESSES

In addition to cooling the air, a true air-conditioning system is designed to provide additional methods of treating the air. Provisions for heating of the space may be contained within the air conditioner. One method of providing heat is by the use of resistance heaters installed in the air circulation chamber of the system. Fresh air is filtered in and mixed with air drawn from the space. The combined air is passed over the now inactive evaporator, over the heater coils, and into the space. Thi
of heating has the advantage of prov
additional process with a minimum of a
equipment and requires very little a
space.

Another method of providing heat i
of the heat pump. A heat pump is
conditioning unit operating in reverse.
of refrigerant is reversed through the
tor and condenser. This action m
refrigerant flowing through the evapo
instead of cool. The evaporator fan bl
culated air across the evaporator, fo
hot air into the training spaces. The h
is more efficient than resistance hea
the mechanical additions require a
space and equipment.

Humidification, the adding of water
another process required of the air con
Detailed description of this process
cussed along with dehumidification in c

BASIC COOLING SYSTEM

The common window type air co
(fig. 6-1) is an example of the bas
contained single unit. The layout of e
and operating principles employed ar
sentative of and essentially the sam
more complex systems presented in this

Room cooling systems usually ha
pacity ranging from one-third ton to
They are installed in windows or direc
outside walls. The unit (fig. 6-2) m
access to outside air for ventilation an
purposes. The condenser is located in
of the cabinet that extends outside the s
Outside air is forced over the coil by
remove heat from the condenser. An a
fan draws room air (or outside fres
through a filter and forces it over th
coil and into the space to be cooled.

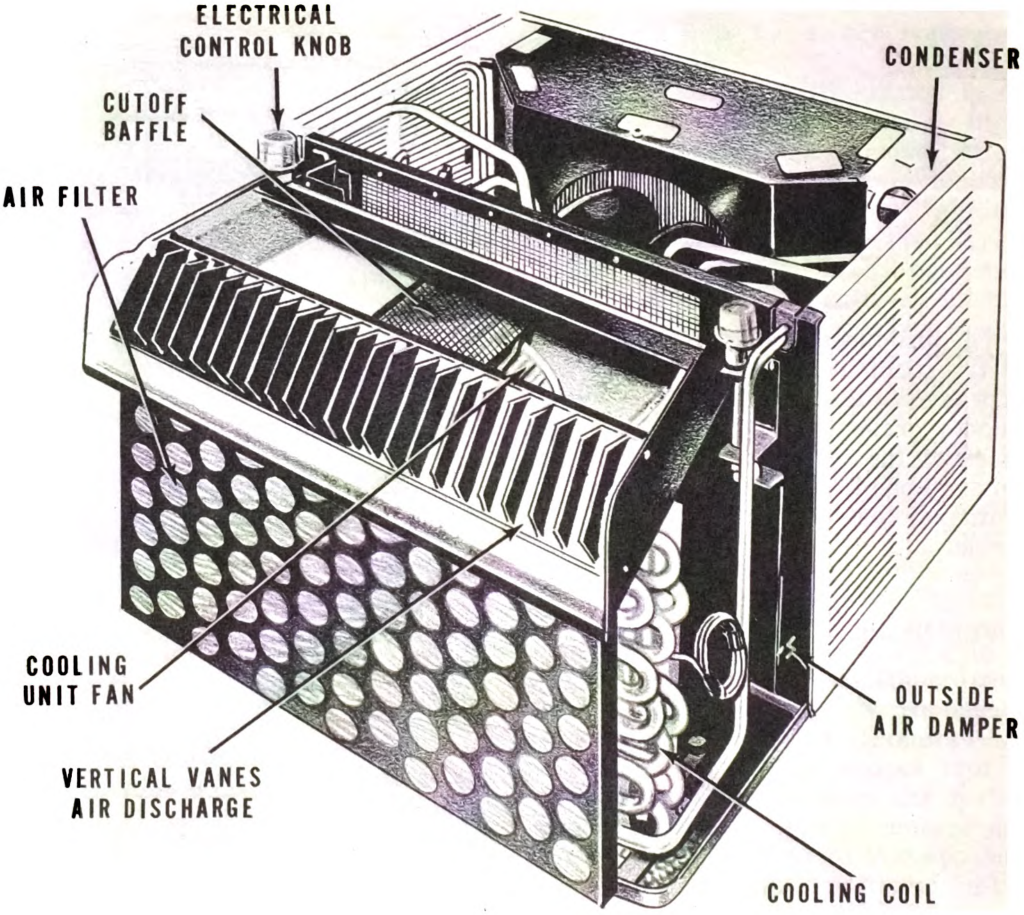


Figure 6-1.—Basic air-conditioning unit.

The basic components contained in the window unit (fig. 6-1) are shown in schematic form in figure 6-3. Cooling of the condenser coil is accomplished by forced air. Circulation of the room air is accomplished by a fan blowing across the evaporator coil. Moisture condensed from the humid air by these coils is collected in a pan at the bottom of the unit. The water drains toward the back of the unit where the condenser fan picks up the drainage in the form of droplets and mist and adds it to the airblast cooling the condenser.

The refrigeration system components are essentially the same as the system described in the preceding chapter. Their purpose and sequence of operation are the same as discussed before.

SINGLE STAGE SYSTEM

One type of the single stage cooling systems that the TD may encounter is the Remington model 10C air conditioner, which is used in the 2F23 training device. The self-contained unit (fig. 6-4) provides conditioned air for the pilot's space and a cool airblast outlet for the instructor. The complete system is situated in three locations. The air-conditioning unit (fig. 6-4) is located in the lower-right-rear corner of the trainer. The main circuit breaker panel (which controls the electrical power) is mounted on the main control panel at the rear of the left side. The control console is mounted in the pilot's compartment on the right side of the cockpit.

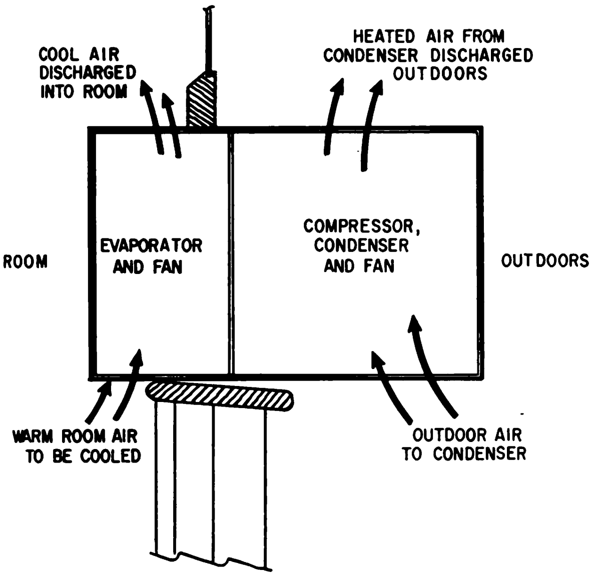


Figure 6-2.—Air distribution.

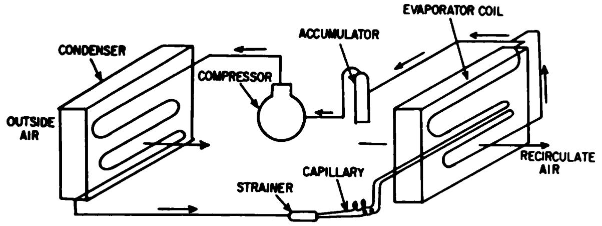


Figure 6-3.—Refrigerant cycle components.

The schematic for the circuit operation is illustrated by figure 6-5. A 220-volt single-phase a-c supply from the main circuit breaker panel is supplied to the relay actuated air-conditioning contactor K1 which is controlled by a START switch S1 and a STOP switch S2. When switch S1 is depressed, a circuit is completed to energize relay K1, which closes the contactor. Closing contact C2 holds the relay closed through the STOP switch S2 which is normally closed. Depressing the STOP switch S2 opens the holding circuit of K1 and power is disconnected from the system. When actuated, the contacts of K1 route 220 volts a.c. to the motor.

The powerline from fuse F2 connects a common line to one side of the evaporator fan motor, condenser fan motor, and terminal R of the compressor motor terminal box. The other powerline from fuse F1 to the other side of the motors is first routed through selector switch S3 and the thermostat S4 on the control console.

When the master selector switch S3 is placed in the FAN position, the circuit is completed to the condenser and evaporator fan motors. The fans or blowers circulate air in an out of the cockpit area through ducts connected to the air-in and air-out ports of the air-conditioning system. (See fig. 6-4.)

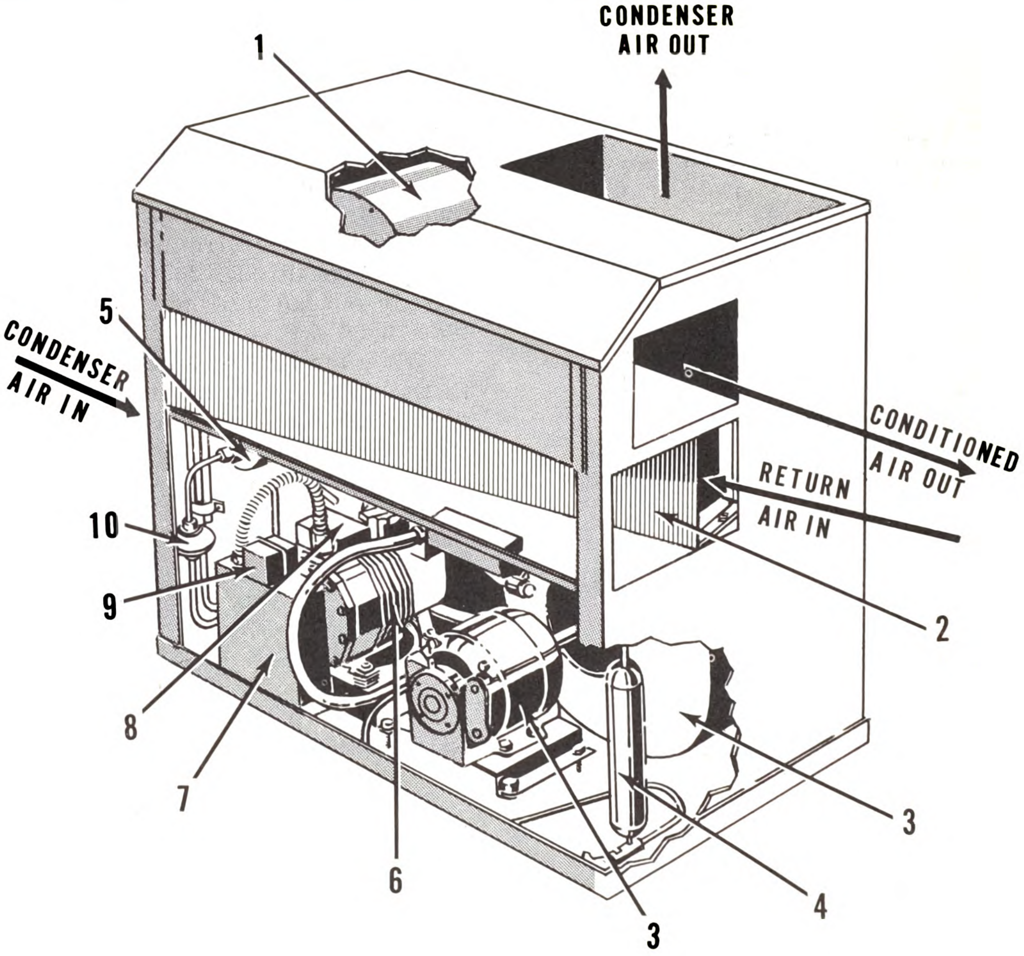
When the master selector switch S3 is placed in the COOL position, the circuit is completed through the thermostat S4 to the compressor motor terminal box (fig. 6-5). The compressor unit uses a capacitor-start, capacitor-run induction motor to drive the 1-hp. sealed compressor. In addition to the starting capacitors, a running capacitor is included to reduce the power factor after the starting capacitors are removed from the circuit. The thermal overload switch S5, a part in the compressor motor terminal box, opens the power circuit to the compressor in case of overheating or excessive current drain.

The compressor and associated refrigeration components provide cool air as long as the thermostat contacts (S4) remain closed. When the predetermined temperature is reached the contacts open removing power from the compressor motor. The circuit, through the right-hand contacts of the master selector switch, still provides power to the evaporator and condenser fan motors which continue to circulate the air.

MULTIPLE STAGE SYSTEMS

Multiple air-conditioning systems are used where large amounts of conditioned air are required. One example of this type system is used where the trainer is mounted in a truck trailer. Operating equipments and training space are condensed into the limited confines of the truck trailer and require conditioned air for proper operation. (See fig. 6-6.)

A multiple system provides the flexibility necessary to efficiently meet widely varying demands. The multiple air-conditioning system has as many refrigeration systems as it has compressors. The multiple air conditioner in figure 6-7 shows the two separate systems. The refrigeration cycle is the same for both



1. Evaporator fan.
2. Conditioned air coil.
3. Condenser fan and motor.
4. Liquid receiver.
5. Expansion valve.
6. Hermetic compressor/motor.
7. Capacitor box.
8. Compressor motor junction box.
9. Relay.
10. Liquid line strainer.

Figure 6-4.—Model 10C air-conditioning unit.

systems. Each system can be operated independently, if necessary. During automatic operation, the number of systems in use at one time depends upon the requirements imposed by the thermostat.

As can be seen by examining figure 6-7, this air conditioner has two compressors, two condenser fans, two heater stages, two evaporators, and one air circulating blower. The control panel provides switches for selecting the mode of operation of the system. The selector switch has five positions as follows: cool, heat, ventilate, off, and service. Also provided on the control panel are six service switches used for maintenance. The electrical connection of the components is illustrated by the schematic diagram in figure 6-8.

The mode of operation of the system (fig. 6-8) is controlled by the master selector switch S1. This selector switch is an 8-wafer, 5-position switch (shown in position C) selecting C (cool), H (heat), V (ventilate), O (off) and S (service). The two stage thermostat (shown in position C) determines from the selected temperature

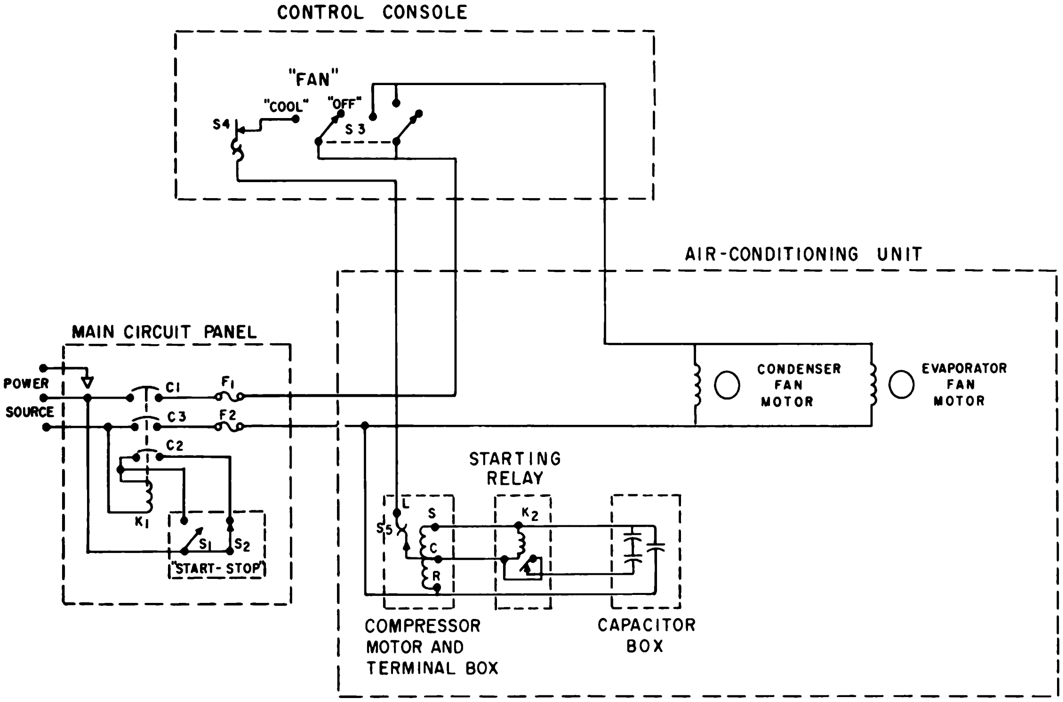


Figure 6-5.—System schematic.

whether the system provides cool or warm air. The humidistat (shown in the humidify position) determines whether moisture is added or removed from the conditioned air. The six service switches (shown in the OFF position) provides the maintenance crew with a means to activate an individual circuit without operating the complete system. The control circuit voltage is brought into the system on line 1 of the power source.

Placing the master selector switch S1 (fig. 6-8) in the V position selects ventilation as the mode of operation. Line 1 voltage (115 v) is applied through terminal E to the center of wafer 1 of switch S1. With the switch in the V position, the circuit is completed through the switch to the circulating fan service switch and then to the control solenoid of the circulating fan. The control solenoid closes and 220 volts is applied to the circulating fan (blower). When S1 is in the V position, the other circuits are not completed, thus only the blower runs.

The system is placed in the cool mode of operation by turning the master selector switch S1 to the C position. The circulating fan also operates with S1 in this position. When the source voltage is supplied to the circulating fan control solenoid, the solenoid is energized and closes contacts C1. The closing of the contacts allows the source voltage to flow through the contacts to the 2d wafer of the S1 switch. The circuit continues from contact C of S1 to the two W contacts (W1 and W2) of the thermostat and contact C3 of the humidistat. With the thermostat in the position shown in figure 6-8, the circuit is completed from contact W1 to contact C1 of the 1st stage cooling thermostat and then to wafer 5 of S1. The circuit continues through to the No. 1 compressor service switch (S2) applying 115 volts to the time delay relay, and the dual pressure cutouts, and then to the control solenoid of the No. 1 compressor. Energizing the control solenoid of the No. 1 compressor starts the compressor and closes contacts C2 which applies voltage to the control solenoid of the condenser fans. Notice that power must be applied to the circulating fan before the compressor can be turned on, and that the condenser fan starts simultaneously with the compressor.

If the No. 1 compressor does not supply sufficient cooling, the second stage cooling

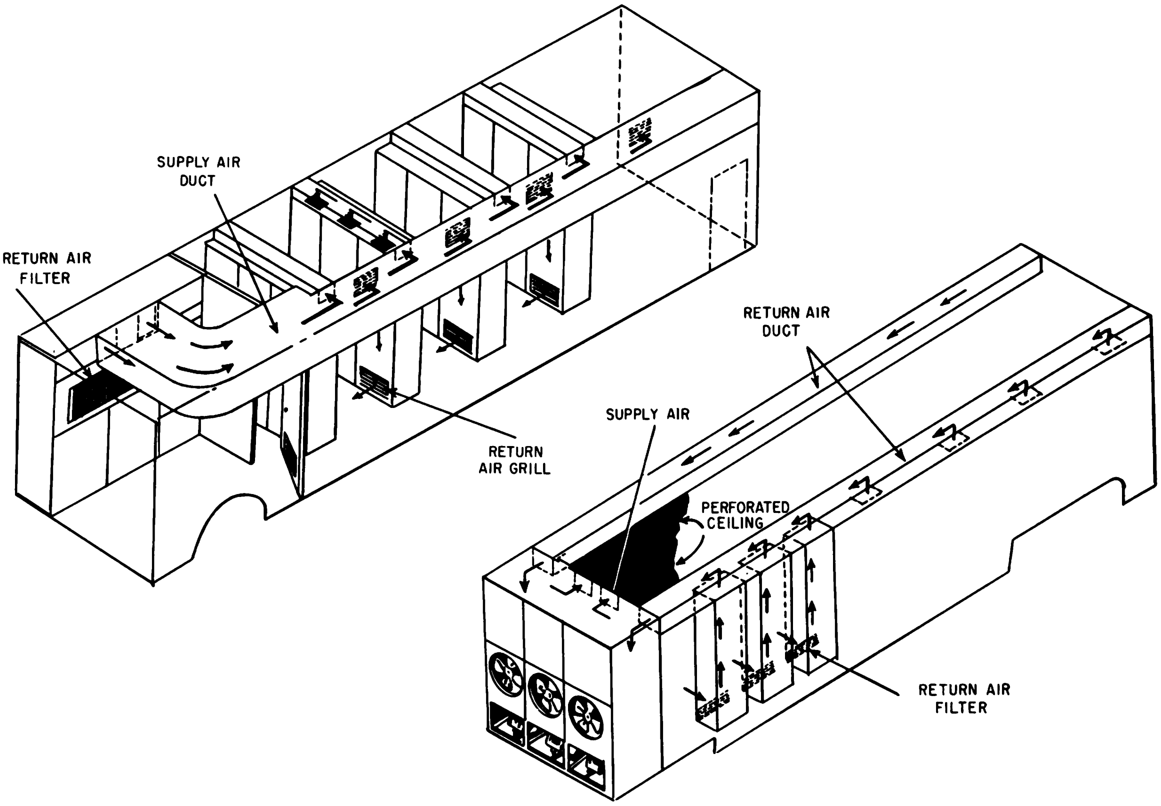
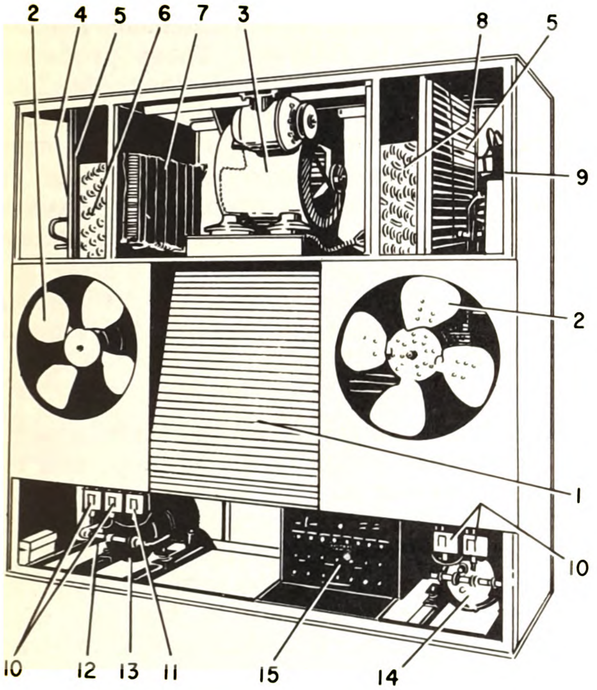


Figure 6-6.—Trailerized air-conditioning system.

thermostat closes (W2 and C2) applying 115 volts to the center contact of wafer 7 of S1. (NOTE: A temperature differential exists between the two stages of the two stage thermostat as discussed in chapter 5 of this course.) With the master selector switch setting the C position, 115 volts from wafer 7 is routed (through contact C of S1) through the No. 2 compressor service switch (S3) and then to the time delay relay. With the contacts of the delay relay closed, voltage from the No. 2 compressor service switch (S3) continues through to the control solenoid of the No. 2 compressor which applies three-phase power to start the compressor. When the master selector switch is placed in the cool position, the time delay relay will not allow both compressors to start at the same time. The No. 2 compressor lags the No. 1 compressor by about 5 seconds (due to the time delay relay) allowing the No. 1 compressor to start before placing the additional starting load of the No. 2 compressor on the power supply.

Dehumidifying is accomplished by cooling the air below its dewpoint with the No. 1 compressor and reheating the air to the proper temperature with the No. 1 heater. When the relative humidity becomes too high, the humidistat closes contact C3 to H3 routing 115 volts through wafer 4 of S1, through the normally closed contacts of the No. 2 compressor control solenoid C3, to the No. 1 heater solenoid. Thus, the 1st stage heater and the No. 1 compressor both operate when the humidistat calls for dehumidification. However, if the 2d stage thermostat closes causing the No. 2 compressor to operate, the normally closed contacts of C3 open, and the No. 1 heater becomes inoperative. The reheat cycle of the No. 1 heater cannot be used if both compressors are required to keep the temperature within the requirements of the thermostat.

The humidifier cannot be turned on when the cooling cycle is selected. Voltage to the humidifier is routed through wafer 3 of S1 which is open except when S1 is in the heat position.



1. Condenser coils—1st and 2nd stages.
2. Condenser fans.
3. Air circulation blower
4. Refrigeration components—1st stage.
5. Air filters.
6. Evaporator—1st stage
7. Heater coils.
8. Evaporator—2nd stage
9. Refrigeration components—2nd stage.
10. High- and low-pressure cutouts.
11. Condenser fan switch.
12. Receiver tank —1st stage.
13. Compressor—1st stage.
14. Compressor—2nd stage.
15. Control panel.

Figure 6-7.—Dual air-conditioner system.

When heating is desired, the master selector switch S1 is rotated to the H position. As in the ventilating and cooling position, the circulating blower control solenoid receives voltage from wafer 1 of S1. The control solenoid of the circulating blower energizes, closing contacts C1, routing voltage through wafer 2 of S1 to contacts W (W1 and W2) of the thermostat and C3 of the humidistat. Assuming that the temperature has dropped sufficiently to close contacts W2 and H2 of the 2d stage thermostat, voltage is routed to wafer 8 of S1 ar control solenoid of the No. 1 heater temperature falls low enough, contacts H1 of the 1st stage thermostat closes. is then routed through wafer 6 of S control solenoid of the No. 2 heater three-phase power to the heater coils. that none of the heaters can come on un circulating fan control solenoid has bee gized, which closes contacts C1.

Humidification can be accomplishe heating cycle when required by the hun When the humidistat contacts C3 and H voltage is routed through wafer 3 of S humidistat. The humidifier atomizes wa the air supply to bring the relative h back up to the comfort zone as selecte humidistat.

When maintaining the system, the selector switch S1 is placed in the S p When S1 is placed in the S position, of wafer 1 routes 115 volts to all si service switches. This allows the in components to be turned on and off as r for maintenance. The complete system operated manually if training conditions r air conditioning and the automatic control would not function properly. The circula should always be turned on before tur either the compressors or the heaters to damage to the equipment.

SYSTEM REFINEMENTS

Some air-conditioning systems uti operation referred to as "automatic down." When cooling is no longer re valves close and the system automatically itself in a pumped-down condition. This that practically all of the refrigerant is into the receiver tank. A thermostatically ted solenoid valve is used in the plac king valve at the output of the receive When cooling is no longer required, th closes allowing no more liquid/gas to to the compressor. This action continu the low-pressure cutout interrupts powe compressor.

Safety controls are incorporated in s that utilize heater coils. The heater safe cuit is designed to prevent heaters from ting when the circulating fan is off. Th cutout switch is placed in the vicinity heaters and opens the heater circuit senses an extremely high temperature.

Most trailerized units have interlock switches which prevent the energizing of the air conditioner when the condenser fan doors are closed.

Sometimes in cold weather the outside air is so cold that the low-pressure cutout does not allow the compressor to start even though the thermostat inside the training space requires that cooling be provided. In this event a ''cold start'' thermostat applies power to the heater of a time-delay relay. After a given time delay, the low-pressure cutout is bypassed so as to energize the compressor control solenoid. After the system starts operating, the automatic control system reverts to its normal operation.

In many systems condenser fans are on constantly when the compressors are operating. On cold days this would cause a very low head pressure, resulting in abnormal operation of the cutout switches. As head pressure decreases, an automatic condenser fan control cuts off one or more of the condenser fans. On very cold days, it would be possible to operate one compressor with no condenser fans running.

MAINTENANCE

To insure the efficient operation of air-conditioning equipment, a program of preventive and corrective maintenance is very important. The procedures for a particular system, as set forth in the manufacturers maintenance manuals, should be closely followed. These procedures differ from one system to another. The information provided in this section is general in coverage to provide the TD with an overall view of the maintenance problems of air-conditioning systems; it should not be used in place of the manufacturer's maintenance manual.

PREVENTIVE

Preventive maintenance is better than waiting for an adverse condition to develop, and then having to correct it. This helps to prevent loss of training time and costs of materials. The important factors in the maintenance of an air-conditioning system are the same three factors that should be observed in the use of all mechanical equipment: cleanliness, lubrication, and periodic inspection.

NavTraDevCen Instruction 10230.1 sets forth the preventive maintenance program shown in table 6-1.

Table 6-1.—Preventive maintenance checklist.

Description	Interval
1. When a unit is equipped with a humidifier and is being used for heating and humidifying, check the water level in the reservoir and fill if needed.	DAILY
2. Remove air filters and clean (at least one complete set of extra filters should be available for each unit).	WEEKLY or every 100 hours of operation
3. Check air circulating fan belt for tightness. (When ''squeezing'' the belt between forefinger and thumb, the belt should not move more than 1 inch. If the belt moves more than 1 inch, then slippage will occur, causing inoperation of the unit. Excessive tightness results in bearing or belt failure and may overload the motor.)	WEEKLY
4. Check the refrigerant sight glass of each stage for indication of a low refrigerant charge. If a low charge is indicated, locate and repair the leak and recharge the system. A low charge is indicated by bubbles or a milky appearance in the sight glass.	WEEKLY
5. Inspect the evaporator coils for cleanliness. If dirty, brush with a long bristle brush and remove dirt with a vacuum cleaner.	WEEKLY

Table 6-1.—Preventive maintenance checklist.—Continued.

Description	Interval
6. Inspect the condenser coils for cleanliness. If dirty, proceed as in item 5.	MONTHLY
7. When the unit is equipped with a humidifier, check the humidifier for operation and lubricate. Use a light oil.	2 MONTHS
8. With a clean dry cloth, wipe off the drier filter, solenoid valves, sight glasses, heat exchanger, and the thermostatic expansion valve. Check the tightness and general condition of each component as it is cleaned.	2 MONTHS
9. Check the heaters to be sure that wires and heater mounting bolts are tight. Be sure heater fins are clean, not bent, and that no wires are touching the heaters.	2 MONTHS
10. Check the mounting bolts and setscrews for tightness on condenser and air circulating fans, fan shafts, and motor shafts. Check the blower wheel and fan scroll clearances.	2 MONTHS
11. Wipe off the compressor with clean dry cloths; look for and make repairs to: a. Loose bolts. b. Loose capillary connections. c. Frayed or broken wires. d. Loose valve caps and gage port plugs. e. Oil leaks beneath compressor and around gaskets.	2 MONTHS
12. MAKE SURE ALL OPEN VALVES ARE BACK SEATED.	
13. Check each stage for refrigerant leaks using a halide torch or other precision leak detector. Check items such as flare nuts, welded connections, bolted connections, all types of fittings, valves, pack nuts, coil manifolds, and return bends. Check any place where oil has been found for refrigerant leaks; repair any leaks found.	2 MONTHS
14. Check the electrical system out completely for: cleanliness, loose terminals, loose connections, loose mounting bolts or screws, frayed wires, and loose components. Also check contactors for normal opening and closing.	2 MONTHS
15. Check all pressure switches for correct settings and tightness of mounting brackets. Refer to the maintenance manual.	2 MONTHS
16. Check overflow pipes in reservoir and drain pans and clean out any dirt or sediment.	
17. Check all clamps, mounting brackets, and tightness of all components.	2 MONTHS

Table 6-1.—Preventive maintenance checklist.—Continued.

Description	Interval
18. Inspect all air inlet and outlet openings for obstructions.	2 MONTHS
19. On all units where applicable, lubricate circulating fan motors and condenser fan motors and all other parts as required.	2 MONTHS
20. Be sure all access panels and cabinet panels are securely tightened in place to prevent air leaks.	2 MONTHS

NOTE: Item 13 of table 6-1 is very important because all oil leaks found in the area of the compressor denote excessive leakage of the refrigerant. The refrigerant is present with the oil in the crankcase of the compressor and any leakage of this oil is a leakage of the refrigerant.

CAUTION: When there is a very serious refrigerant leak, the concentration of the halogen gas being burned in the acetylene mixture is high, and this results in a deep purple, lazy flame of the leak detector. This lazy purple flame is producing phosgene gas, a deadly poision with the odor of new cut hay. Do not use a torch in a confined area and do not breathe the gas coming off a lazy purple flame of a leak detector. Just as soon as a purple flame occurs, withdraw the test probe. Make certain there is plenty of circulating air to blow this gas out of the confined space. Then use the torch to locate the leak. Repair leak as necessary.

As stated in table 6-1, cleaning is best accomplished by using a vacuum cleaner or soft hairbrush. The ventilating fins on the condenser and evaporator are made of very thin metal and bend easily. Extreme care should be taken not to bend the fins as bent fins obstruct the passage of air.

Maintenance and overhaul on motors should be performed in accordance with the instructions contained in the manufacturer's maintenance manual.

When placing new equipment into operation, and even when starting up a system that has been out of operation for a period of time, you should give the entire system a checkover. Use a straightedge to insure that the compressor and motor pulleys are in line. Check the belt tension. Remember that if there are two or more V-belts on one drive, they must have identical tension; otherwise, one will carry more than its share of the load, overheat, and wear out. When one V-belt of a multiple set must be replaced, change the whole set, in order to insure uniformity of length and tension.

Refer to the manufacturer's maintenance manual for various setup and inspection procedures.

CORRECTIVE

Faulty operation of any air-conditioning system is indicated by very definite symptoms. The symptoms differ according to air and water-cooled systems. These symptoms may be caused by one or more incorrect conditions which must be eliminated in a step-by-step process of corrective measures. The trouble symptoms, causes, and corrections, included in tables 6-2 and 6-3, are general in coverage to present examples of possible troubles. However, the manufacturer's maintenance manual generally contains troubles and remedies as applied to the specific system and should be used when maintaining the equipment.

Quiet operation of air-conditioning systems is not only desirable but is very important where training spaces are concerned. To test for excessive noise, operate the system at maximum load. Then listen, both outdoors and indoors, for noisy operation of the equipment.

Locate the noise sources in respect to parts of the equipment, and try to analyze them. A frequent cause of operating noise, for example, is an unbalanced fan. Loose belts, faulty motor bearings, or misalinement of components can result in noisy operation of the unit. The defects, if neglected, may become a major repair problem.

In correcting defects, however, personnel should not tamper with such components as hermetically sealed refrigeration equipment, or factory calibrated automatic controls. Refer to the maintenance manual for the scope of field

Table 6-2.—Trouble diagnosis chart—water-cooled condensers.

Symptom or difficulty	Condition may be due to	Correction
High head pressure	Air or noncondensable gas in system.	Purge air from condenser.
	Inlet water warm or insufficient water flowing through condenser.	Check for obstruction in condenser water supply strainer or partially closed valve.
		Check water regulating valve.
	Too much gas in condenser.	Clean condenser water tubing.
	Condenser clogged or limed.	Draw off refrigerant into service drum.
Low head pressure	Too much water flowing thru condenser.	Regulate water inlet valve.
	Water too cold. Hand operated valve, unthrottled.	Reduce quantity of water as above.
	Leaky suction or discharge valves.	Test with gages. If leaking, replace.
	Shortage of refrigerant.	Add refrigerant.
High suction pressure	Overfeeding of expansion valve.	Regulate expansion, check bulb attachment.
	Leaky suction valve.	Remove head, examine valve disks, or rings. Replace if worn.
	Discharge valves leak slightly.	Examine valves, replace if necessary.
Low suction pressure	Restricted liquid line and expansion valve or suction screens.	Pump down, remove, examine, and clean screens.
	Insufficient gas in system.	Check for gas shortage.
	Too much oil circulating in system.	Check for too much oil in circulation. Remove oil.
	Improper adjustment of expansion valves.	Adjust valve to allow more flow.
	Stuck or frozen expansion valve.	Tap or thaw expansion valve as necessary.
Compressor is intermittent during high pressure output	Insufficient water flowing through condenser; clogged condenser.	Determine if water has been turned off. Adjust water regulating valve. Check for limed condenser or obstruction in water strainer.

Table 6-2.—Trouble diagnosis chart—water-cooled condensers.—Continued.

Symptom or difficulty	Condition may be due to	Correction
	High pressure cutout incorrectly set.	Check setting of high pressure cutout.
	System overcharged with refrigerant.	High pressure cutout may be tripping due to insufficient condenser capacity because condenser tubes are submerged. Draw off refrigerant.
	(See high head pressure.)	
Compressor is intermittent during low pressure cutout	Coils in refrigerators clogged with frost.	Defrost coils.
	Liquid suction or expansion valve screens dirty.	Pump down and clean screens.
	Thermal bulb on expansion valve has lost its charge.	Detach thermal bulb, hold in the palm of one hand, gripping the suction line with the other hand. If flooding through is observed, the bulb has not lost its charge. If not flooding through, replace expansion valve.
	(See low suction pressure, above.)	
Compressor runs continuously	Improper functioning of the low pressure control switch.	Adjust or replace switch.
	Overloaded compressor.	Start additional compressor if system is arranged for isolating loads carried by more than one unit in operation.
	Shortage of refrigerant (with temperature control).	Test refrigerant, if insufficient, add proper amount necessary. Test for leaks.
	Suction or discharge valves leak badly.	Test valves, if leaking, remove head of compressor and repair or replace.
	Head gasket blown between cylinders.	Replace gasket.
Compressor noisy	Vibration because not bolted to foundation rigidly.	Bolt down rigidly.
	Too much oil in circulation causing hydraulic knock.	Check oil level.

Table 6-2. —Trouble diagnosis chart—water cooled condensers. —Continued.

Symptom or difficulty	Condition may be due to	Correction
	Wear of parts such as piston pins, eccentrics, etc.	Determine location of cause. Repair or replace compressor.
Oil leaves crankcase	Leaking piston rings or worn cylinder.	Replace rings or compressor, or rebore and refit.
	On starting, suction pressure drop too rapid.	Short cycle compressor on starting.
Oil does not return to crankcase	Valve in oil return line closed or stuck shut.	Open.
Compressor will not start	Overload tripped; fuses blown.	Reset overload, replace fuses and examine for cause or condition.
	No charge of refrigerant in system operated by a low pressure control switch.	Recharge.
	Solenoid valve on liquid line closed.	Replace or repair.
	No voltage or low voltage.	Check for voltage.
Water valve chatters	Water pressure too high.	Reduce water pressure.
Cylinders and crankcase sweating	Too much oil in circulation.	Examine for conditions of refrigerant and oil charge. Correct the condition.
	Liquid refrigerant in circulation.	
Crankcase frosting	Liquid refrigerant returning to compressor.	Adjust expansion valve.

Table 6-3.—Trouble diagnosis chart—air-cooled condensers.

Symptom or difficulty	Condition may be due to	Correction
High head pressure	Airflow to condenser restricted.	Remove loose articles that would tend to restrict the flow of air.
	Air or noncondensable gas in system.	Purge air from system.
	Overcharge of refrigerant.	Draw off refrigerant into service drum.
Low head pressure	Leaky suction or discharge valve.	Test with gage, if leaking, replace.

Table 6-3.—Trouble diagnosis chart—air-cooled condensers.—Continued.

Symptom or difficulty	Condition may be due to	Correction
	Shortage of refrigerant.	Add refrigerant.
Low suction pressure	Restricted liquid line, expansion valve screen, or suction screens.	Pump down, remove, examine and clean screens.
	Insufficient gas in system.	Check for gas shortage.
	Too much oil circulating in system.	Check for too much oil in circulation. Remove oil.
	Improper adjustment of expansion valves.	Adjust valve to give more flow.
	Stuck or frozen expansion valve.	Tap or thaw expansion valve as necessary.
High suction pressure	Over feeding of expansion valve.	Regulate expansion valve, check thermal bulb attachment.
	Leaky suction or discharge valves.	Test with gages; if leaking, replace.
Compressor is intermittent during high pressure cutout	Insufficient air flowing through condenser.	Remove any debris that would block the airflow.
	High pressure cutout incorrectly set.	Check setting of high pressure cutout.
	System overcharged with refrigerant. High Pressure cutout tripping due to insufficient condenser capacity.	Draw off refrigerant into service drum.
	Air or noncondensable gases in system.	Purge air from condenser.
Compressor is intermitten during low pressure cutout	Coils in refrigerators clogged with frost. Suction or expansion valve screens clogged.	Pump down and clean screens.
	Thermal bulb on expansion valve has lost charge.	Detach thermal bulb from suction line and hold in palm of hand, gripping the suction line with the other hand. If flooding through is observed, bulb has not lost its charge. If no flooding through is observed, replace expansion valve.

Table 6-3.—Trouble diagnosis chart—air-cooled condensers.—Continued.

Symptom or difficulty	Condition may be due to	Correction
	(See low suction pressure above.)	(See low suction pressure above.)
Compressor runs continuously	Shortage of refrigerant.	Test for leaks. Add refrigerant.
	Suction or discharge valves leak badly.	Test valves. If necessary, repair or replace.
	Head gasket blown between cylinders.	Replace gasket.
	Liquid, suction or expansion valve screen clogged. (With temperature control.)	Pump down and clean screens.
	Improper control settings, stuck electrical contacts.	Readjust control settings, clean and adjust contacts.
Compressor noisy	Vibration; not bolted to foundation rigidly.	Bolt down rigidly.
	Too much oil in circulation causing hydraulic knock.	Check oil level.
	Wear of parts such as piston pins, eccentrics, etc.	Determine location of cause. Repair or replace compressor.
	Excessive high head pressure.	Check reason for high head pressure and correct.
	Lack of lubricating oil.	Check oil level and add as required.
Oil does not return to crankcase	Valve in oil return line closed or stuck shut.	Open.
Compressor will not start	Overload tripped, fuses blown.	Reset overload, replace fuses and examine for cause.
	No charge of refrigerant in system operated by a low pressure control switch.	Recharge.
	Solenoid valve on liquid line closed.	Replace or repair.
	No voltage or low voltage.	Check for voltage.
Oil leaves crankcase	Leaky piston rings or worn cylinders.	Replace rings or compressor, or rebore and refit.

Table 6-3.—Trouble diagnosis chart—air-cooled condensers.—Continued.

Symptom or difficulty	Condition may be due to	Correction
	On starting, suction pressure drop too rapid.	Short cycle compressor on starting.
Cylinders and crankcase sweating	Too much oil in circulation. Liquid refrigerant returning to compressor.	Examine for conditions of refrigerant and correct the condition.
Crankcase frosting	Liquid refrigerant returning to compressor.	Adjust expansion valve.
Head gasket leaks	Head bolts stretched or washers crushed.	Examine gasket, replace if necessary. Tighten head bolts. Replace washers. (NOTE: Head bolts are generally tightened with a torque wrench.)

maintenance. If the repair of the system can not be accomplished by authorized adjustments or repairs, assistance should be requested in accordance with instructions contained in Training Devices Guide NavExos P-530.

Repair Equipment

Small tools required for repair operations are hammers, hacksaws, tube and wire cutters, piping tools, wrenches, pliers, screwdrivers, files, and hand levels. Also needed is such equipment as a halide torch, gas torch, pressure gages, and a refrigerant charging assembly. (See fig. 6-9.) Many air-conditioning manufacturers furnish a set of special tools for maintaining the specific system of equipments.

Service gages come in the form of a gage manifold with the necessary valves and connections. The pressure gage is on one side, and the compound gage on the other. (See fig. 6-10.) The gages are mounted on a manifold which has three line connections and two shutoff valves that separate the gage openings from the centerline connection. This manifold enables the repairman to connect his gages to the system and allows him to charge and discharge a system, check the pressures, add oil, and any other required operations.

As shown in figure 6-10, the manifold gage (A) is connected by a flexible charging line to the suction side (D) of the compressor. The pressure gage (B) is connected to the discharge side (C) of the compressor. The manipulation of the manifold shutoff valves for the various operations is illustrated in figure 6-11.

To install the gages shown in figure 6-10 proceed as follows:

1. Remove the cap of the compressor suction service valve, and turn the valve stem outward as far as it will go to its back seat. This closes off the service gage port from the compressor crankcase and suction line.
2. Remove the plug from the gage port, and replace it with a flared tube connector fitting.
3. Connect the flared tube fitting with the flexible tube on the 30-inch vacuum, 150-lb compound gage side of the manifold.
4. Move the valve stem of the suction service valve inward, off the back seat, about one-half turn, and tighten the gland nut.
5. Crack the valve on the compound gage side of the manifold, to allow air in the flexible line to excape through the service drum connection.
6. Repeat the same procedures to connect the pressure gage side of the gage manifold to the service port of the DISCHARGE service valve.

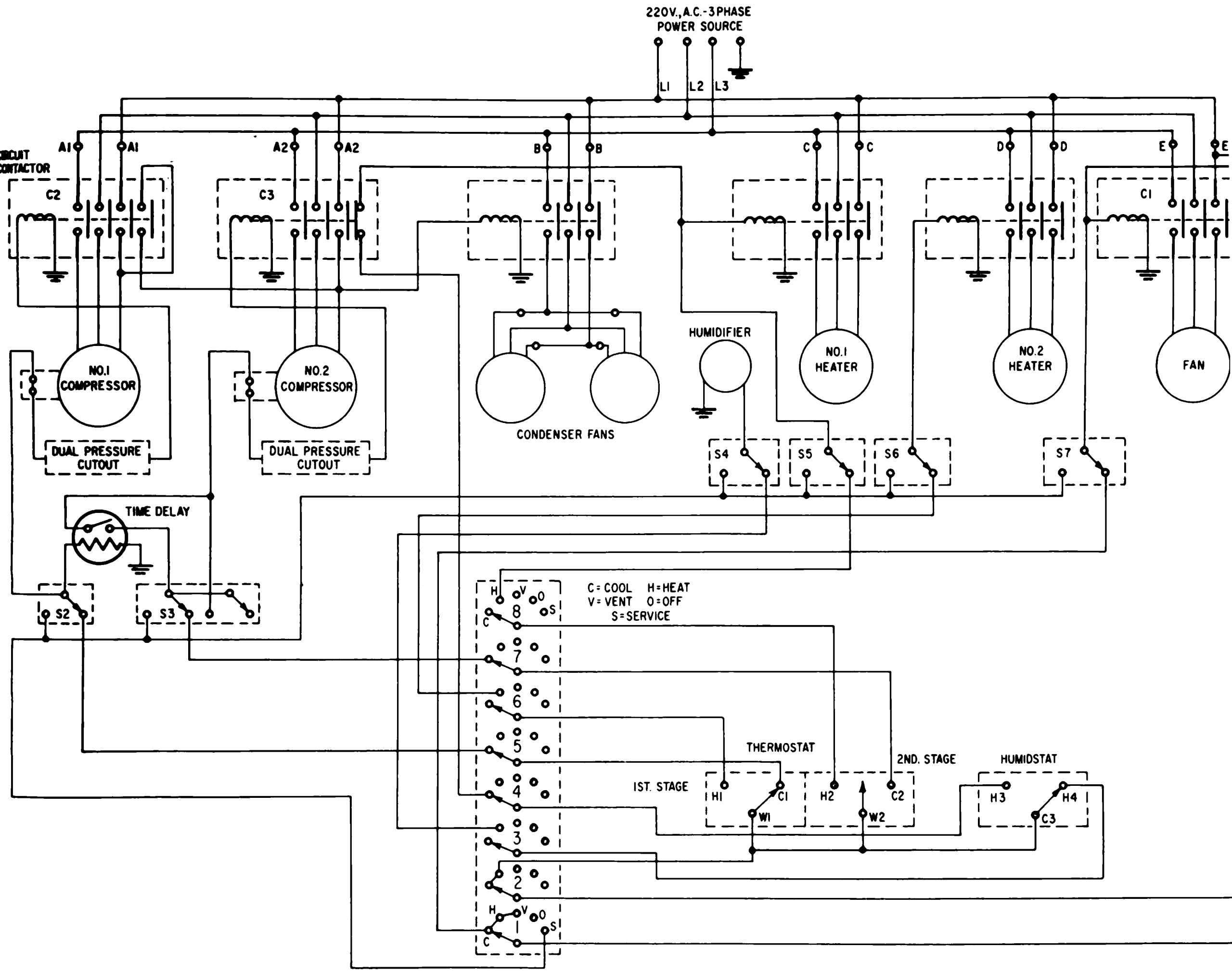


Figure 6-8.—Schematic of dual system.

To open the condenser service valve (if installed), remove the valve cap, and then turn the valve stem outward 8 or 10 turns, or until it back seats. Tighten the gland nut, and replace the valve cap, pulling it up until it just compresses the gasket. Next, slightly open the compressor discharge service valve. Never start a compressor with the discharge service valve closed.

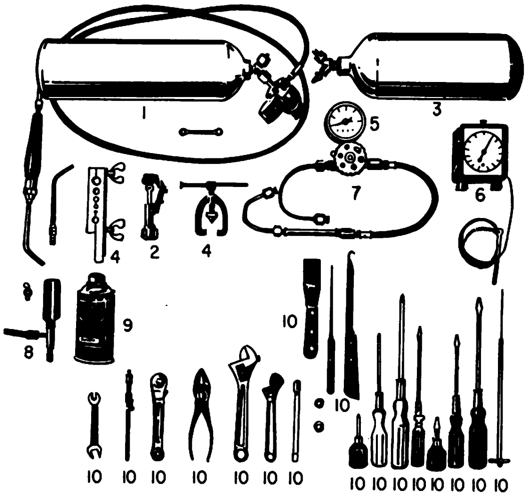
Open the receiver stop (or king) valve by removing the cap and cracking the valve until the compound gage reads 50 psi. Then close the valve, and tighten the gland nut.

Reading Pressures

High and low side pressures are a good indication of how the system is functioning. A comparison can be made of the readings against the prescribed readings in the man facturer's maintenance manual.

The manifold gage is set up as shown figure 6-11 (A). Note the positions of t three-way suction and discharge service valve Pressures may be read while the compress is idle or running.

When reading pressure or adding refrigera always be sure to purge (bleed) the tubing li or lines first. This is done by leaving t connections loose at one end of the tubi (at the service valve end for adding; at t manifold gage end for reading pressures) a admitting some refrigerant into the lines. Ne tighten all connections and set the valves in t appropriate positions as shown in figure 6-11 (



1. Presto-lite torch.
2. Tube cutter.
3. Gas tank.
4. Flaring tool - anvil and split bar.
5. Pressure gage.
6. Thermometer.
7. Set of fittings.
8. Halide torch.
9. Can of refrigerant oil.
10. Miscellaneous handtools.

Figure 6-9.—A typical set of tools needed for servicing air conditioners.

Air and moisture normally present in the tubing are admitted into the sealed system if purging is not done.

Bleeding the System

Any air or moisture in a system must be removed. The presence of air is indicated by pressure and temperature readings that will vary from the prescribed readings in the maintenance manual. The air in the system mixes with the refrigerant vapor, but does not mix with the refrigerant liquid. To remove air from the system, it is only necessary to remove the refrigerant vapor. This is accomplished by bleeding (purging) the low side of the compressor with the gages installed and valves set as indicated in figure 6-11 (B). The procedure is as follows:

1. Set the manifold gage valves so the compound valve is closed and the pressure valve is open.
2. Start the compressor and crack both the suction and discharge service valves.
3. Observe that the pressure gage needle begins to drop as the refrigerant vapor is expelled.

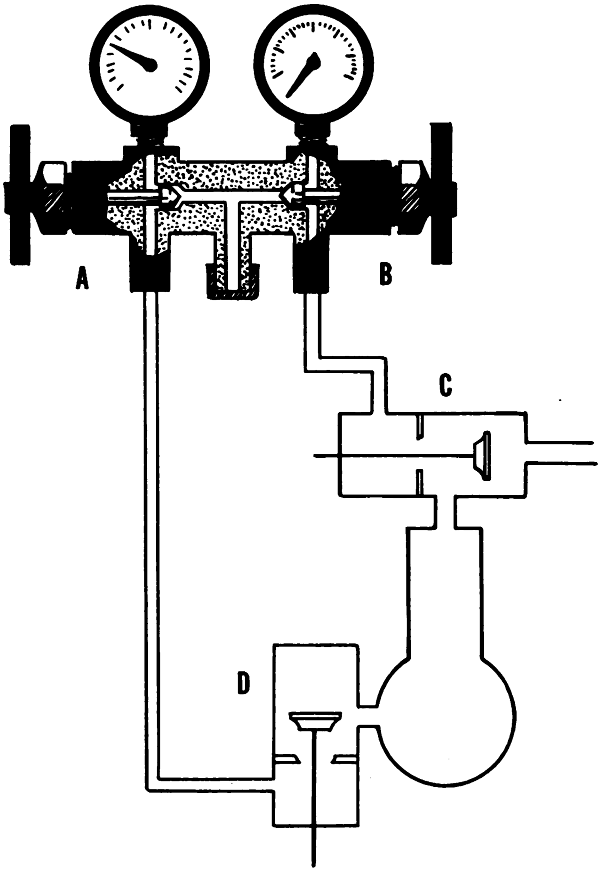


Figure 6-10.—A manifold service gage.

4. When the pressure reaches the prescribed level, turn the suction and discharge service valves to their normal operating positions.

Evacuating and drying the unit is an important part of all assembly work. As nearly as possible, the system should be clear of air, moisture, and other foreign matter. The general steps for evacuating and drying a unit are as follows:

1. Evacuate.
2. Charge with CO_2 to the prescribed pressure and heat as directed.
3. Evacuate and check for moisture. If moisture is present, repeat steps 2 and 3.
4. Charge with refrigerant gas and heat as prescribed.
5. Evacuate.
6. Charge with refrigerant to the prescribed level.

The most careful evacuating and purging will not clean a dirty unit that was carelessly put together. A good vacuum pump should be used to remove as much air as possible from the unit. A rotary pump produces the best vacuum in

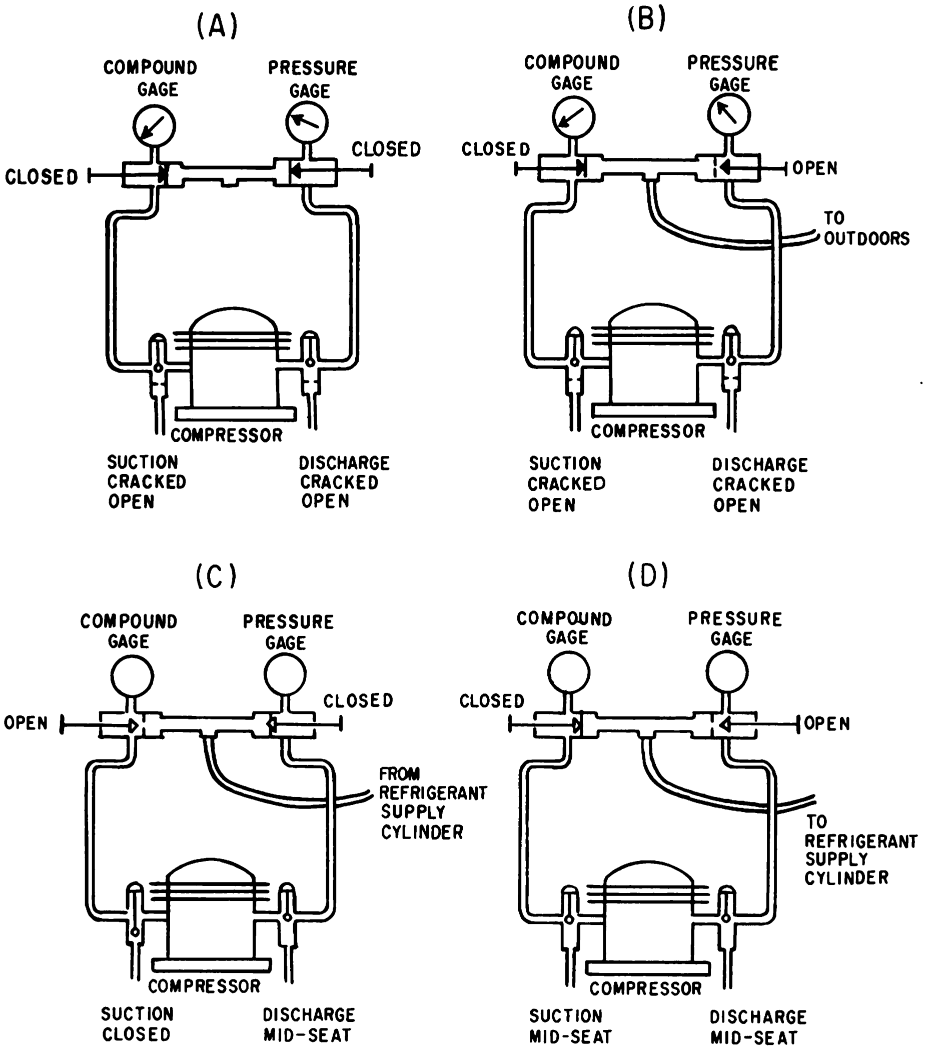


Figure 6-11.—Service valve connections. (A) Reading pressure; (B) purging the system; (C) charging to low side; (D) charging to high side.

most cases. However, the best pumps will not remove all the air. A pump that produces a 28-inch vacuum is only removing 28/30 of the air or 93 percent. In a 28-inch vacuum, moisture must be heated to 100 F to be vaporized and thus be pumped out as water vapor.

To efficiently remove moisture, the unit must be heated to a temperature that vaporizes the moisture in the little cracks and crevices that exist throughout the system. The unit may be operated for part or all of this operation to insure that all pockets in the compressor, motor windings, and bearings are agitated to release trapped air. Duration and temperature of evacuation are prescribed in the maintenance manual for the equipment involved.

Carbon dioxide has an affinity for moisture and circulating it in the system helps to remove moisture. Charging with refrigerant gas and again evacuating reduces the amount of air to about 0.8 percent of the air originally in the system. The remaining air may be removed by purging the condenser after the system has been in operation for a short time.

Where available, a moisture indicator should be used to determine that the system is free of moisture before the refrigerant is introduced into the system.

Adding Refrigerant Vapor to the Low Side

Refrigerant is available in large tanks and small disposable cans. The small disposable can is convenient for adding small quantities of refrigerant. A suggested procedure is as follows:

1. Connect the gages and service valves as shown in figure 6-11 (C).
2. Set the valves as indicated in figure 6-11 (C). The suction service valve is closed, allowing the incoming vapor to enter the compressor.
3. Hold the refrigerant tank or can below the level of the inlet to the compressor. This allows the vapor to enter the system rather than the refrigerant liquid.
4. Start the compressor.
5. When the prescribed suction and discharge pressures are reached, stop the compressor.
6. Place the service valves in their normal operating positions and disconnect the gage set and tubing lines.

Adding Liquid Refrigerant to the High Side

This procedure differs from the foregoing by adding liquid rather than vapor. The suggested procedure is as follows:

1. Set the manifold gage valves and gages as shown in figure 6-11 (D).
2. Purge the connecting lines.
3. Hold the refrigerant supply can higher than the inlet valve and pointed downward. With the can upside down the liquid flows out of the can rather than vapor.
4. The compressor must have been idle long enough for the pressure in the liquid line to drop and the temperature of the line lowered to approximately the ambient temperature.
5. Gravity will allow the liquid refrigerant to flow down through the tubing line into the liquid line of the system. To accomplish this, the pressure must be greater in the supply can than in the system.
6. Continue adding refrigerant until the liquid sight glass is clear. If the sight glass appears milky or has bubbles in it, the system does not have a full charge.
7. When the prescribed amount of refrigerant has been added, place the service valves in their normal operating positions and disconnect the gage set and tubing lines.

Testing For Leaks

Small leaks in a system cannot be located, regardless of the method of detection, unless the pressure inside the system is from 40 to 50 psi. There is always sufficient pressure in the high pressure side of the system, but on the low side, pressures are sometimes only slightly above zero psig. To test for leaks, therefore, you must increase pressure on the suction side by bypassing discharge pressure from the condenser to the suction side, through the service gage manifold, when the compressor is shut down.

If you are going to test for leaks in a system, make sure that the working space is well ventilated, before you light off the torch. Remember, this vapor is highly flammable.

The halide torch, illustrated as item 8 in figure 6-9, is the best device for testing for leaks in Freon-12 systems. Keep the flame of the torch as low as possible, so that even a small refrigerant leak will cause the flame to change color. The torch should show a blue flame when lighted, and this changes to a greenish flame when it contacts a refrigerant leak. If it burns with a greenish flame when lighted, there is refrigerant in the air. Go over all joints, especially flared tube nuts, fittings, sweat connections, and gasketed joints.

A soap and water solution can be used to test any system. It can be applied with a soft brush, but you must wait until all bubbles have disappeared from the solution. Then, if bubbles appear after it has been brushed on to the joints or tubing where leakage is suspected, you know that they are caused by the escaping refrigerant.

Copper Tubing

The tubing used in all air-conditioning systems is specially annealed copper tubing. The purpose of the annealing is to make the copper flexible and to adapt the tubing for flaring and bonding. Tubing may be obtained in sizes from three-twelfths in. to three-fourths in. in outside diameter. When ordering tubing, be sure that dehydrated, annealed, and seamless tubing is specified. A more detailed description of copper tubing may be found in Basic Handtools, NavPers 10085-A.

A hacksaw with very fine teeth can be used for cutting tubing; however the tube cutter illustrated as item 2 in figures 6-9 is recommended.

One method of connecting tubing uses flares and flare nuts. (See fig. 6-12.) A special tool is available for the making of the flare and is illustrated as item 4 of figure 6-9. The split flared block contains several holes for different sizes of tubing. The anvil tool has a chamfered tip which is tightened into the tubing and opens the walls of the tubing into a flare. (See fig. 6-12.)

The bending of copper tubing is very important to the successful operation of the line. The tubing must be carefully bent as illustrated in figure 6-12. A special bending tool is available and must be used for bending large sizes of tubing. The smaller sizes of tubings such as is used in air conditioners, can be bent by hand. However, a neater job is accomplished by using a bending tool. The main concern is that the tubing be bent so that it does not apply any strain on the fittings and that the tubing wall is not crimped or collapsed by the bend. The recommended minimum radius to which tubing may be bent is between five and ten times the diameter of the tubing.

Another method of connecting copper tubing is soldering. (See fig. 6-13.)

The sequence of steps for soldering as illustrated in figure 6-13 is as follows:

1. Cut tubing to proper length. Remove the burr from the inside and outside of the tubing with a file or scraper.
2. Clean the outside surface of the tubing with sandpaper.
3. Clean the inside surface of the tubing with a wire brush, sandpaper, or sandcloth.

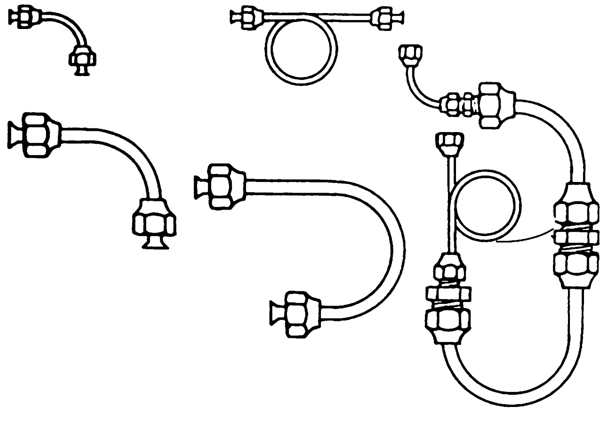


Figure 6-12.—Copper tube flares, flare nuts, and bends.

4. Apply flux to the inside surface of the fitting. The most satisfactory flux to use is made of alcohol and rosin. When acid flux is used, it tends to corrode the fittings and makes them unsightly.
5. Apply flux to the tubing ends and fittings.
6. Apply heat with a torch. (See item 1 of fig. 6-9.) When the solder melts upon contact with the heated fitting, the proper temperature for soldering has been reached. Remove the flame and feed the solder to the joint at one or two points until a ring of solder appears at the end of the fitting.

Safety Precautions

In general, the safety precautions to observe with regard to the refrigerant in an air-conditioning system are as follows:

1. Never mix different refrigerants in the same system. This rule applies to Freon-12 and Freon-22; a system designed for Freon-12 requires redesigning if Freon-22, or any other Freon-type refrigerant, is to be substituted.
2. Do not fill a refrigeration system until the piping has been evacuated, cleaned, and dried free of moisture. Watch your moisture-indicating devices to see if the refrigerant has become contaminated with moisture.
3. Never operate the air-conditioning system when the refrigerant supply in the system is very low. The first result would be that a layer of insulating frost would cover the evaporator, and no cooling would result. Then, because of nonstop operation of the unit motor failure and damage to the compressor could occur.
4. Do not allow any part of a refrigeration system to become overheated.
5. Never use a torch around a system that operates with an explosive refrigerant.
6. When the refrigerant must be drawn out of a system into a cylinder, remember that 85 percent full is the maximum safe capacity of a gas cylinder.
7. In charging a system, keep a close watch upon gages to avoid overcharging.
8. When you loosen a connection in which Freon-12 is confined, wear goggles to protect your eyes. If Freon-12 does come in contact with your eyes, use sterile mineral oil or olive oil as a soothing application. DO NOT RUB YOUR EYES. If possible, report at once to the medical officer.
9. If Freon-12 comes in contact with your skin, treat it as you would a frostbite.

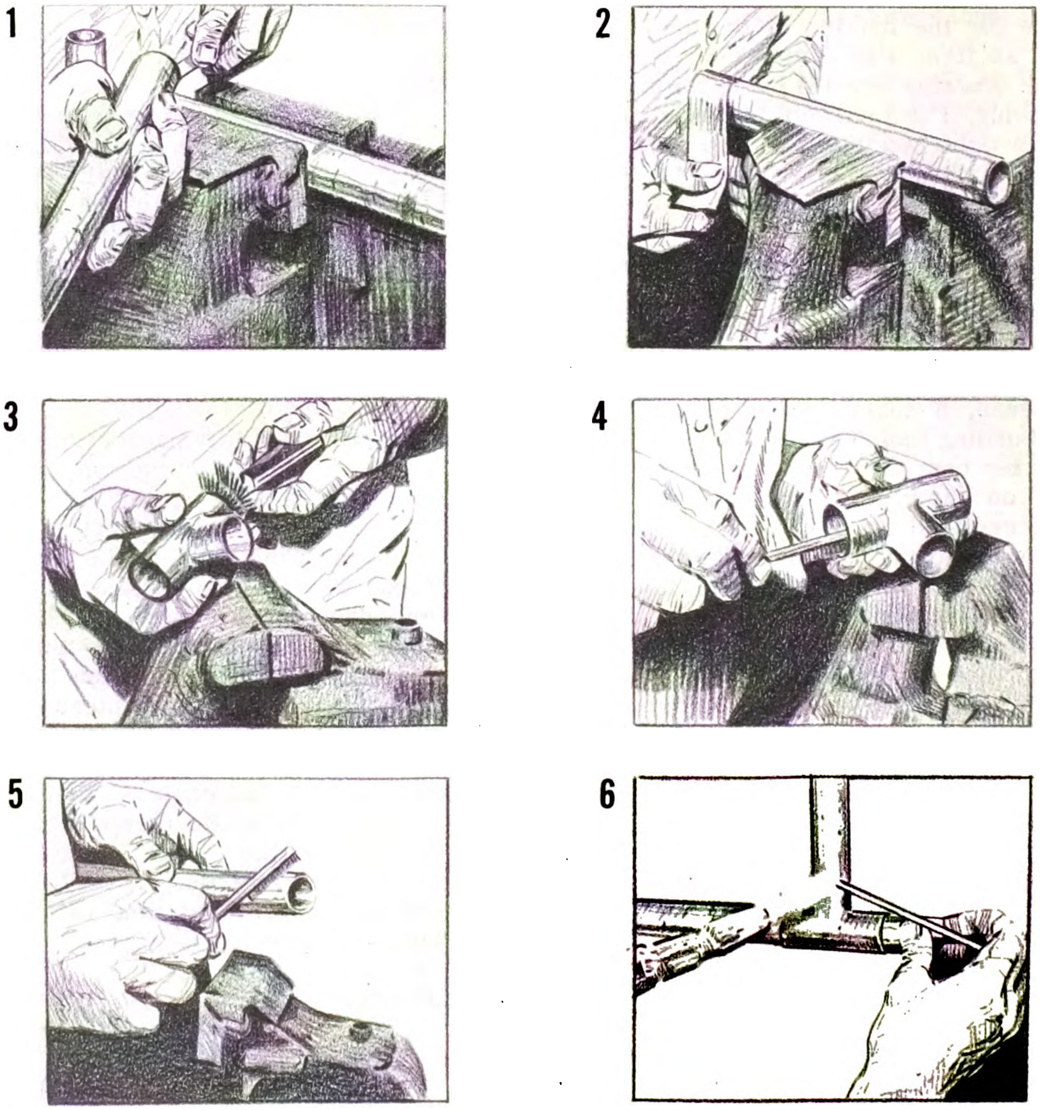


Figure 6-13.—Steps for soldering copper tubing.

10. Any person who is overcome in a space that lacks the necessary oxygen because of a high concentration of Freon-12 must be moved to a fresh airspace, and then given artificial respiration.

11. Turn off all power when instructed by the service manual to avoid the automatic starting controls starting the system which might result in injury to personnel.

12. Always operate the compressor with the service valve in the open position to prevent possible physical damage to the compressor.

13. Release pressure from the system before brazing or soldering.

CHAPTER 7

CLOSED CIRCUIT TV

In previous years when television was mentioned, most people immediately thought of entertainment. The growth of television has been so great that is is now utilized in schools, industrial plants, business establishments, stores, shops, and all branches of the government. However, these applications are not for entertainment, but for performing a specific job efficiently by the use of a closed circuit television (CCTV) system.

Specific applications of CCTV include the following examples:

1. Observing distant points such as blindspots for aircraft traffic control around hangars and taxi areas.
2. Observing locations inaccessible to humans such as monitoring water levels inside a boiler.
3. Controlling the handling of radioactive materials.
4. Instructing groups of trainees located at different places.
5. Enlarging an image as seen under a microscope or telescope to permit more viewers to observe the image simultaneously.
6. Viewing combat operations and communicating with combat crews by viewers at various locations.
7. Providing visual presentations for operational trainers.

In studying the CCTV system it becomes apparent that its operation closely resembles commercial telecasting. The major difference is the methods of transmitting the picture and sound. In CCTV, several methods of transmission are used to bring the signals from the camera to the receiver/monitor. Units may be physically connected using telephone or coaxial cables for short distances. For greater distances, or when numerous receivers/monitors are involved, transmission is normally accomplished through the same media as commercial transmission. This may be accomplished by using a standard transmitter on specially assigned frequencies. When a receiver is used, the receiver is generally a standard television receiver. The monitor is basically the same as the television receiver except that the set utilizes no tuner or associated circuits.

SYSTEM COMPONENTS

A closed circuit television consists of three basic units: a camera or pickup unit, a control unit, and a monitor. Each unit contains numerous circuits, many of which are discussed in detail in Basic Electronics, NavPers 10087-A. This chapter discusses the various circuits contained in the three basic units and the timing or scanning sequence utilized by a system. Device X8F1 is described in this chapter as an example of a CCTV. Other CCTV devices are discussed in chapter 8 of this course.

PICKUP UNIT

The pickup unit, generally referred to as the camera, starts the sequence of events which occur in the CCTV system. A lens is used for focusing an image on a photosensitive (light) tube. The type of lens is determined by the size of the scene to be televised, and may be a normal, wide-angle, or telephoto lens. The size of the camera unit varies from small palm size mobile units to large units mounted on special platforms.

As shown in figure 7-1, one or more cameras can be connected into the system to receive the desired picture (video) and route it as an electronic signal to the control unit.

CONTROL UNIT

The control unit (fig. 7-1), as the name implies, is the heart of the system. This unit

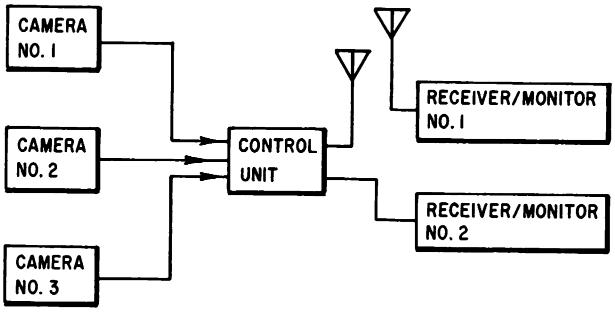


Figure 7-1.—CCTV simplified block diagram.

connects all the other units of the system together. Synchronizing signals are generated and supplied to both the camera and the receiver/monitor. Vertical and horizontal deflection pulses synchronize the sweep circuits within the camera and receiver/monitor.

Video signals from the camera are amplified and distributed to the receiver/monitor. The output signals from the control unit contain vertical and horizontal blanking, sync, and video signals.

RECEIVER/MONITOR

The picture producing unit is commonly referred to as the receiver/monitor unit. The receiver and the monitor, as explained previously, differ basically only in the circuits contained in each unit. The media of transmission between the receiver and monitor units being different requires that the receiver employ additional circuits. (The media employed for the receiver is air, while the media for the monitor is normally direct via cables.) The standard TV receiver contains the same circuits as the monitor, and in addition contains the antenna, tuner, RF amplifiers, and IF amplifiers to receive the transmitted signals from the control unit.

After the IF stage of amplification, the receiver and monitor units are basically the same. Power supplies provide the various voltages needed for the circuits; audio amplification is basically the same as that used in standard radio receivers; synchronization is accomplished through the use of a sync circuit with horizontal and vertical sync signals used to control the horizontal and vertical sweep circuits; and video amplification is accomplished through the various video circuits.

SCANNING

If a picture printed from a photoengraving (for example, a halftone picture in a newspaper) is examined with a magnifying glass, it is easily determined that it is composed of a large number of dots. The lightness or darkness of the picture or areas within the picture is determined by the amount of separation between the individual dots. The dots are the elements that make up the picture.

A television picture is formed in a similar manner. There is, however, one very important difference. In the picture made from the photoengraving, all of the elements of the picture are viewed simultaneously. In the television picture, the elements are presented individually, one after the other, but in such quick succession that the observer sees the picture as a whole. To transmit images in this manner, it is necessary to employ a system of scanning; that is, the image is swept by an electron beam in a systematic manner so that during a period of time all parts of the image are swept by the electron beam. Likewise, in the receiver, where the image is reconstructed, a similar system of scanning is employed.

The principle of scanning can be illustrated by the following example. Assume that you have a flashlight that can produce a very narrow beam of light and that you wish to view a picture on the wall of a dark room. Obviously, because of the narrow beam, you must view a portion of the picture at a time. If you can manipulate the light very fast, you can view the picture in the same manner as the picture would be produced in television. To do this you would start at the upper left-hand corner of the picture and move the beam rapidly to the right along the top of the picture. When the right-hand edge of the picture is reached, turn off the beam, and swing it rapidly to the left and one spot width lower. Turn the light on and again sweep it rapidly to the right. Each sweep of the light is a scan line, and in commerical television there are 525 lines to a picture. Thus, when you reach the bottom right-hand corner of the picture, you have completed a frame and the light is turned off and moved to the upper left-hand corner of the picture to start the scanning process over again.

In camera tubes, an electron beam of small diameter is formed and given the desired velocity by the electron gun located in the neck of the tube. Deflection (sweeping) of the electron beam across the mosaic is accomplished by the deflection coils that are positioned around the neck of the tube.

A simplified illustration of scanning is shown in figure 7-2. The beam begins its scan at the upper left-hand corner of the mosaic and moves horizontally along line 1 toward the right. The globules shown are exaggerated in size to simplify the illustration. All of the globules in line 1 are in the bright part of the mosaic. Therefore, they have lost the same number of electrons and accumulated uniform positive charges. As the beam sweeps across these globules, the charges are neutralized, and a relatively steady current flows from the metal coating of the mosaic plate down through a load resistor, through the B supply to the electron beam, and back to the associated globules. The same situation prevails while line 2 is being scanned.

A part of the image is located in line 3, and there is not a steady flow of current

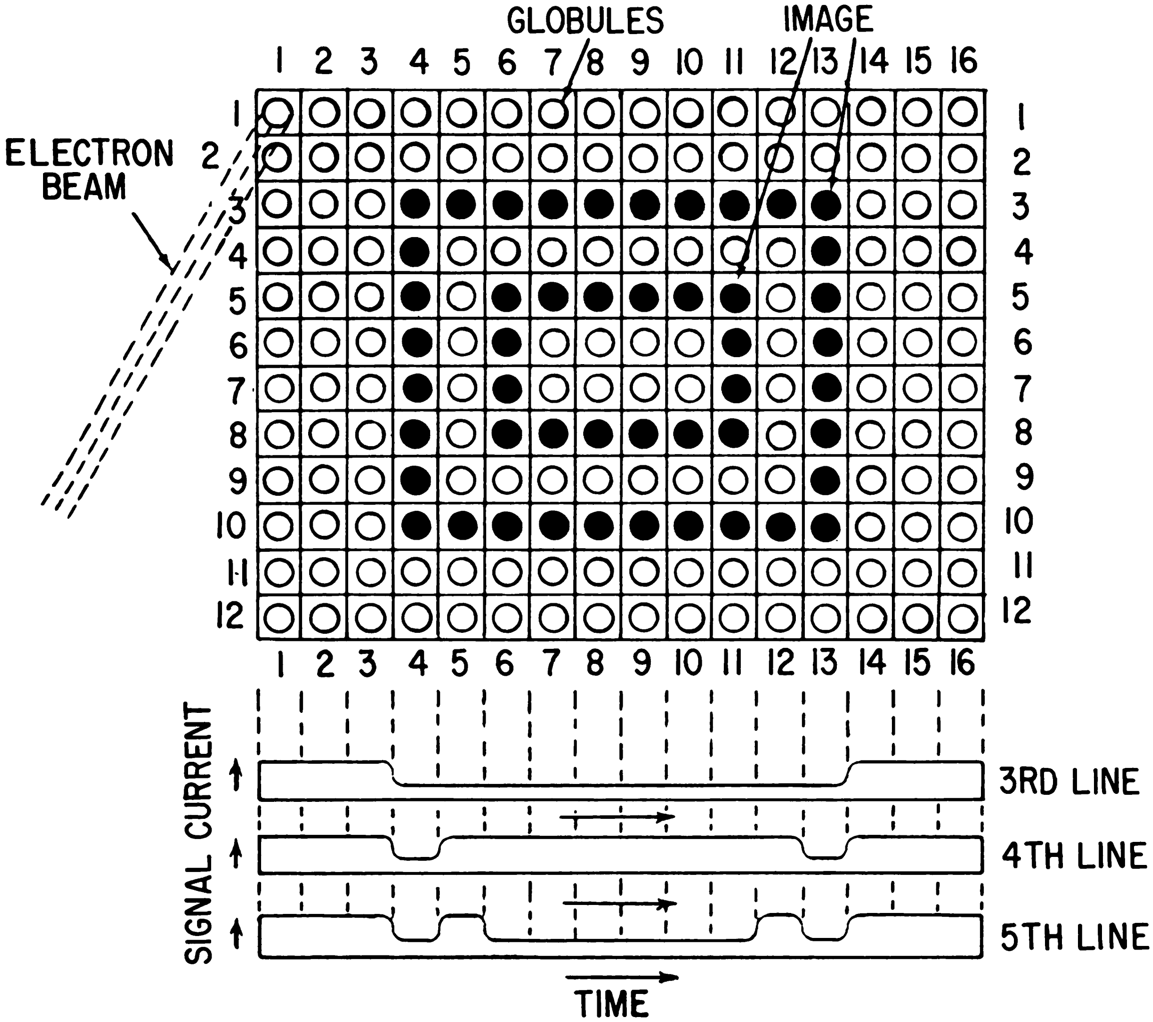


Figure 7-2.—Simplified illustration of scanning.

through the load resistor as the beam traverses this line. The current flow is steady until the fourth globule is reached. From 4 through 13 the globules have been charged slightly, and the discharge current through the load resistor is less when the beam sweeps across the black globules. Beginning with globule 14, the output current increases again. In line 4 the current through a load resistor is steady until the beam reaches globule 4, then decreases until the beam reaches globule 5. The current through the load resistor then increases and remains steady until the beam reaches globule 13. The current then decreases while the beam is on globule 13 and increases when the beam strikes globule 14. The current through the load resistor then remains steady through the rest of line 4.

When the electron beam scans line 5, the current through the load resistor is steady while the beam scans globules 1, 2, and 3; decreases for globule 4; comes back to the steady value for globule 5; decreases for globules 6 through 11; goes to the steady value for globule 12; decreases for globule 13; and then returns to the steady value for the rest of line 5. The relative strengths of the signal currents are shown at the bottom of figure 7-2.

In a practical camera tube, the globules are extremely small and close together, so the picture will have great detail. Therefore, there must be many changes in current during the course of a single scan. The flow of the tiny pulses of current through a resistor develops signal voltages at the input of the video amplifier. In order that all of these signal voltages may be passed through the amplifier, it must be capable of passing a wide band of frequencies.

BANDPASS REQUIREMENTS

When we speak of the bandpass requirements of an amplifier we are referring to the range of frequencies which must pass through the amplifier. For code work where only one frequency is concerned, a very narrow bandpass (as low as 100 cycles) is used. The bandpass required for television is much greater and some idea of these requirements may be gained from the following explanation.

Assume that each line to be scanned contains 1,000 globules, each insulated from the others; it is assumed also that the diameter of the electron beam is approximately that of a globule and that each adjacent globule has a different charge.

In standard home television sets used in the United States, 525 lines are scanned by the electron beam in tracing over the entire mosaic surface of the camera tube. As will be shown later, some of these lines are lost during the retrace (blanking) time. The surface of the mosaic is completely scanned 30 times in 1 second. Therefore, the number of lines scanned in 1 second is 525 x 30 = 15,750; this is called the horizontal sweep frequency.

The number of globules (each having a charge proportional to the intensity of a particular picture element) contained in 1 line is assumed to be 1,000. Therefore, the number of picture elements in the image each second is 15,750 x 1,000 = 15,750,000.

If a complete cycle is assumed to be the change in signal voltage developed when the beam passes across 2 successive globules, then the frequency is 15,750,000 ÷ 2 = 7,875,000 cps. In order to reproduce all of the picture elements perfectly, the transmitter and receiver circuits must be able to pass, without distortion, a band of frequencies approximately 7.87 mc wide. The quality of the picture detail is called resolution.

In actual practice, it is not necessary to pass a band of frequencies this wide. There are less than 1,000 picture elements per line, and each globule of the light-sensitive compound may not be charged differently from its neighbor. These and other considerations permit a bandpass of 4 mc to allow satisfactory results.

Assume that a bandpass of 4 mc is all that is possible. How much horizontal detail (bits of picture detail on a horizontal line) is then possible? The period of a 4-mc signal is 0.25 μsec which is the time required by the electron beam to scan across 2 adjacent elements. Because 15,750 lines are scanned in 1 second, the period of 1 line is 63.5 μsec. From this, the time used during the retrace (10.2 μsec) must be subtracted to give the actual period of 1 line. The period of 1 line is then 53.3 μsec, and the number of cycles per line is 53.3 ÷ 0.25 = 213 (approx.). The number of elements per line is therefore approximately 2 x 213 = 426.

Vertical detail depends on the number of horizontal lines scanned per picture frame. This may be illustrated by the use of figure 7-2. Assume that, in line 3, each black dot (picture element) is divided into 2 dots and placed one above the other within the confines of line 3. When the beam scans the line, both dots are covered simultaneously and only one signal is available at the output. If the beam width is made smaller and twice as many lines are scanned, a signal is produced from both black dots; that is, the vertical detail is improved.

In the complete scan of one picture frame, many lines are lost during flyback time. These lines are therefore not effective in producing vertical detail. It may be assumed that there are 380 horizontal lines that are effective in producing vertical detail. The number of picture elements per frame is 426 x 380 = 161,880; and at 30 frames per second, the total number of cycles produced is 161,880 x 30 = 4,856,400.

As previously stated, a bandpass of 4 mc will give satisfactory results.

FLICKER

The eye retains an image for a fraction of a second (about 1/15 second) after the image is formed on the retina. This characteristic of the eye is utilized in moving pictures and television. Actually, it is because of this characteristic that it is possible to have moving pictures or television.

Moving-picture films are composed of a series of individual pictures (frames) that are shown on the screen in quick succession. The illusion of motion comes about because the figures may be displaced slightly in succeeding frames; and if enough frames are shown per second, the figures appear to move because of the rapid sequency of the frames and the persistance of vision. At approximately 15 frames per second the motion appears continuous, but there is a pronounced flicker. At 24 frames per second, some flicker is present; however, it is much less objectionable than at 15 frames per second. To further reduce the flicker, a special shutter arrangement is used. The shutter cuts off the light from the screen while a new frame is moved into position. It also cuts off the light from the screen once more while the picture frame is stationary. Thus the shutter divides the presentation of every frame into two equal time intervals. This has essentially the same effect as increasing the frame frequency to 48 frames per second.

INTERLACE

In television, similar problems are encountered. To keep flicker from becoming objectionable, 30 complete frames per second are shown. Flicker is further reduced by the use of interlaced scanning, which has essentially the same effect as increasing the frame frequency to 60 frames per second. The horizontal scanning speed and bandpass requirements of the composite TV signal remain the same.

Interlaced scanning is illustrated in figure 7-3. As has been mentioned before, bandpass considerations, the problems of synchronization, and the necessity for detail lead to the choice of 525 horizontal scanning lines per frame. To reduce flicker by means of interlaced scanning, the electron beam scans the odd-numbered lines first and then the even-numbered lines. Thus, two scans (fields) are necessary to complete one frame. For example, as shown in figure 7-3, the sweep for the first field begins on the left side of line 1. The beam moves across the image plate at a slight downward angle (pulled downward by the vertical deflection coils). At the end of the line, the electron beam is blanked out during the retrace to the left side of line 3. This process is continued until the middle of line 525 is reached (only 25 lines are shown in the figure). Therefore, 262.5 lines are scanned in the first field. When the beam reaches the middle of the last line, it is blanked out and returned to the middle of line 2 where the trace for the second field starts. The even-numbered lines are scanned in sequence until the end of line 524 is reached. At that instant the beam is blanked out and returned to the beginning of line 1, and the whole process is repeated.

In order to keep the movement of the electron beams in both the camera and picture tubes in step, and in order to blank out the signals from the picture tube during the horizontal and vertical retrace periods, synchronizing and blanking signals are transmitted by the transmitter.

COMPOSITE SIGNAL

Blanking signals (voltages) are used in both the camera tube and the picture tube control circuits to cut off the electron beam at the end of a horizontal scan line so that the return trace is not active in producing picture signals at the transmitter or picture elements at the

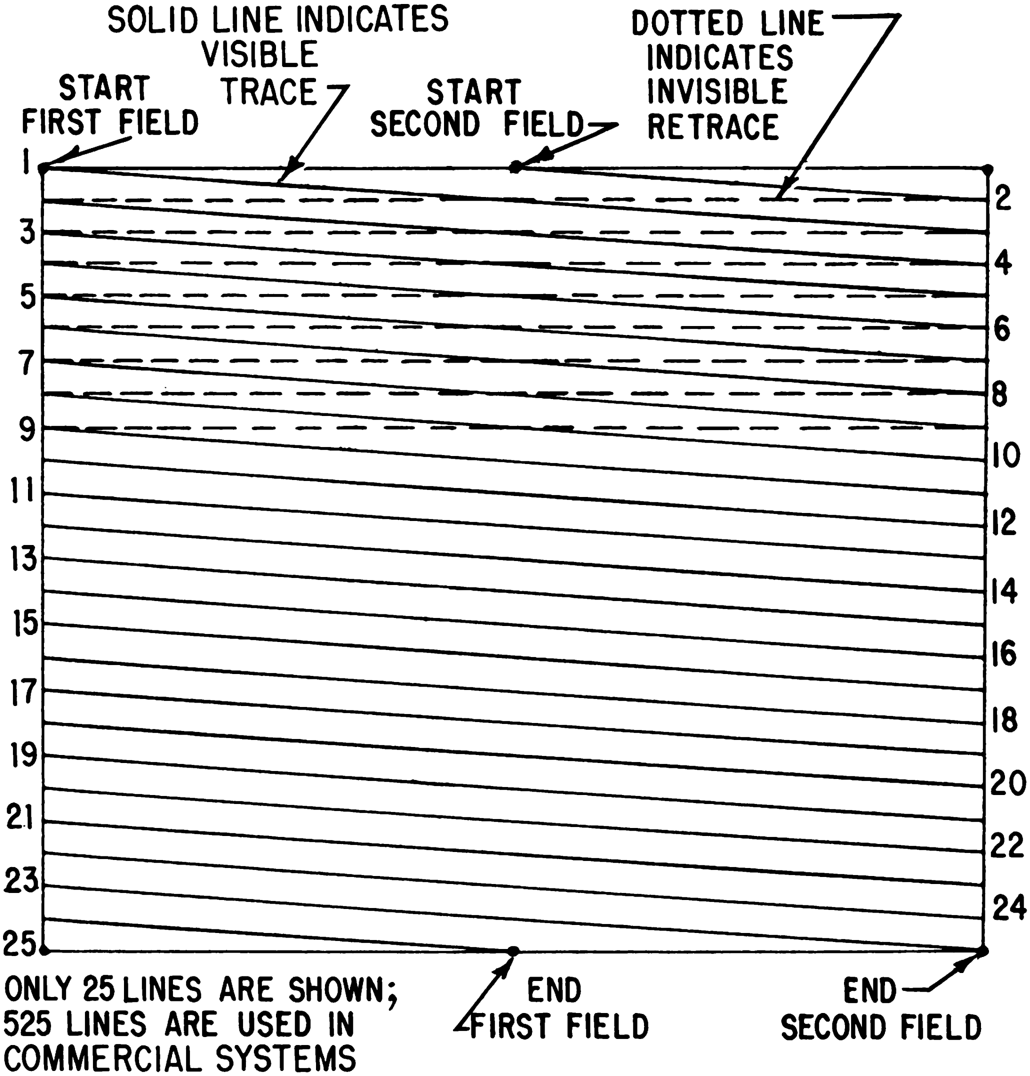

SOLID LINE INDICATES VISIBLE TRACE
DOTTED LINE INDICATES INVISIBLE RETRACE
START FIRST FIELD
START SECOND FIELD
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
ONLY 25 LINES ARE SHOWN; 525 LINES ARE USED IN COMMERCIAL SYSTEMS
END FIRST FIELD
END SECOND FIELD

Figure 7-3.—Interlaced scanning.

receiver. Blanking signals are also used to blank out the vertical return trace following the scan of each field.

Included with the blanking voltages (actually superimposed on them) are the synchronizing pulses that trigger the horizontal and vertical sweeps in the receiver/monitor. The horizontal sync pulses trigger the horizontal sweep (at the correct instant) 15,750 times a second. The vertical sync pulses trigger the vertical sweep (at the correct instant) 60 times a second.

For the horizontal scan, the sequence is as follows:

1. The signal is blanked out when the trace reaches the right-hand side of the screen.
2. An instant later the horizontal sync pulse arrives and brings the trace to the left-hand side of the screen.
3. The next horizontal trace begins.
4. An instant later the blanking pulse is removed and the trace is visible until it reaches the right-hand side of the screen.

For the vertical scan, the sequence is as follows:

1. The signal is blanked out at the end of the first field (at the end of line 262.5).
2. The vertical sync pulse arrives and brings the trace to the middle of line 2 at the top of the screen.
3. The next vertical sweep begins.
4. The blanking signal is removed.

During the second field, the lines missed on the first field are filled in.

In order to keep the horizontal sweep locked in step during the vertical -retrace period and in order to produce interlaced scanning, the vertical sync pulses have a special serrated form and are preceded and followed by equalizing pulses. The composite video signal (the complete signal, including video and sync pulses), particularly the vertical and horizontal sync pulses, have more meaning when the method of separating the pulses is described later in the chapter.

All television receivers must perform essentially the same functions. They must be able to select the desired carrier frequency, amplify the required band of frequencies, separate and demodulate the video frequencies and audiofrequencies, separate and utilize the sync pulses, and finally reproduce the picture on the screen and the sound at the loudspeaker. How well each of these jobs is accomplished depends, in a large measure, on the design and the quality of the TV receiver.

When the signal in closed circuit TV is sent from the camera unit to the viewing unit via cables, there are no antenna problems. However, where the control unit contains a small oscillator which furnishes an amplitude modulated video signal, the viewing unit must have a tunable receiver.

SEQUENTIAL SCANNING

Sequential scanning differs from interlace scanning in the method of moving the electron beam down the screen. The sequential system can be compared to reading a page of print. Each line is read in turn instead of every other line as in interlace scanning.

If 60 complete frames are scanned per second, flicker (line crawl) does not exist. However, unless the system has a very broad bandpass, resolution would decrease due to the high video frequencies being produced. The horizontal scanning speed would have to be doubled and would introduce other problems with extremely high frequencies.

OPTICAL SYSTEM

One of the most important parts of the television system is the optical system. This system must capture all the detail of the viewed scene so the pickup tube can transm
a good picture.

The principles of light, contained in Trade
man 3 & 2, NavPers 10376-A, should be r
viewed as background information prior
studying the following description of the le
unit, lens, and iris. References to photograph
characteristics also apply to the televisi
optical system characteristics.

LENS CHARACTERISTICS

The optical term lens is applied to a pie
of glass which is bound by two spherical su
faces or a plane and a spherical surface. It
also commonly used when referring to a phot
graphic objective. The term photographic obje
tive indicates that several simple lenses ha
been combined as elements in an optical instr
ment which is used to form a real image of
object.

The lens has many principles which a
peculiar to photgraphy. If the TD wishes
make the best use of the lens, he should
thoroughly acquainted with these principl
and terms. Consequently, a discussion follo
on each of the terms considered to be of t
most basic importance.

Focal Length

The image formed by a lens is sharp on t
the screen at the point where the margin
rays and those passing through along its optic
axis meet. If these incident rays are parall
when they reach the lens, they converge
come into focus at a distance of one foc
length behind the lens. The focal length of
lens is equal to the distance from its optic
center to the camera focal plane when it
focused upon an object at infinity. The foc
length of a lens is an inherent factor th
cannot be changed. This factor is determin
by the formation (diameter and thickness) a
curvature of a lens. Focal length is frequent
employed to indicate the size of a lens. Thu
a lens labeled as an 8-inch lens (F. L. 8 i
indicates that when it is focused on a poi
at infinity the distance from its optical cent
to the focal plane is 8 inches; and that a di
tance of 8 inches is the nearest distance
which such a lens will sharply focus an imag
The thickness and the diameter of the le
affect the focal length. The index of refracti
for the lens material also determines the foc
length.

The focal length of a compound lens is often referred to as equivalent focal length. This means that the focal length of the modern lens is being compared to the focal length of a simple thin lens which would give an image the same size.

When a lens is used in a TV camera, it must be placed at a certain distance from the focal plane to obtain a sharp image. As shown previously, this distance is actually controlled by the focal length of the lens and the lens-to-object distance. Hence, with a given object size and a given object distance, the lens focal length determines the size of the image; that is, the longer the focal length of the lens the larger the image, and the shorter the focal length of the lens the smaller the image. The effect that focal length has upon image size is illustrated in figure 7-4.

Figure 7-4 shows that when two cameras having two different focal lengths are placed at an equal distance from an object, the images formed have different dimensions. At any given distance the lens focal length controls the image size. The lens with a focal length of 12 inches forms a smaller image than the lens with a focal length of 24 inches. In fact, the image formed by the 24-inch lens is twice as large as the image formed by the 12-inch lens.

The Field of a Lens

The beam of light passing through a lens is cone shaped (due to refraction). The large ends of the cone spreads over a circular area at the focal plane. The usable portion of this lighted circle is the field of the lens. (See fig. 7-5.)

Two lines drawn from the center of the lens to opposite ends of any diameter of this field form the angle of field of that lens. Likewise, lines may be drawn from the lens to opposite ends of the focal plane, and the angle formed is the angle of view. The field of a lens, the angle of field, and the angle of view are all illustrated in figures 7-5 and 7-6.

By studying figure 7-6, it should be apparent that the angle of view is a flexible term governed by the size of the focal plane used and its position in the field of the lens. If the focal plane is moved too far aside from the axis of the lens, part of it might lie outside the angle of field. In this case, the portion of the focal plane which is outside the field would receive no image. The remaining section of the focal plane could cover a very narrow angle of view.

No lens produces a usable image over its entire field. The image formed around the edges of the field is always blurred. This blurring is true to a greater extent with some lenses than with others. Nevertheless, the angle of view of a lens is always a smaller area within the field of a lens and never as large as the field of the lens.

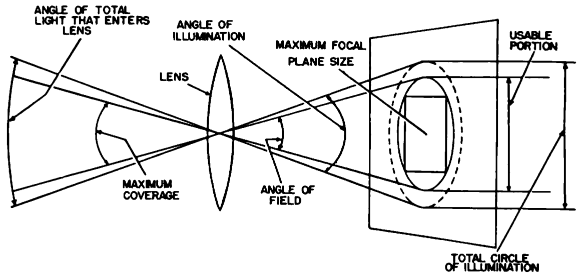


Figure 7-5.—The field of a lens.

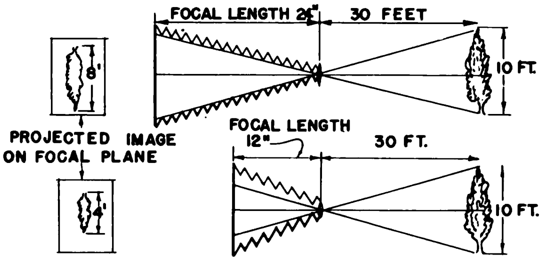
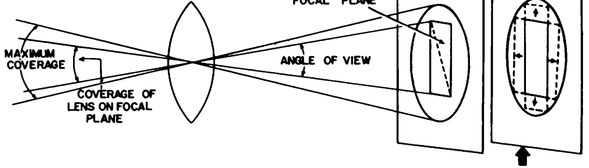


Figure 7-4.—Effect of focal length on image size.



FOCAL PLANE CAN BE MOVED WITHIN USABLE PORTION OF THE CIRCLE OF ILLUMINATION AS SHOWN BY THE DOTTED LINE

Figure 7-6.—Angle of view.

TYPES OF LENSES

The desired type of image or the size of camera coverage require different types of lenses. The size of the lens (fig. 7-7) varies from small and short to large and long. The purpose of the various lenses vary from the wide-angle lens for large area coverage, to the telephoto lens for narrow coverage at long distances.

A special lens called the "zoom" lens is used for special effects. This lens can be varied from the normal visual coverage to distant closeups. In some installations the lens is manually adjusted, while in other TV cameras it is motor driven. The lens may be adjusted either manually or by an automatic motor-driven device.

FOCUSING

Adjusting or changing the distance between the focal plane and the lens is termed focusing. To aid in accurate focusing, cameras of the view and press type have a focusing screen which is a piece of ground glass placed at the focal plane of the camera on which the subject is focused. This device provides a definite plane upon which the eyes may focus, and insures that the image formed by the lens is focused upon the same plane. The focusing screen should never be confused with the focal plane.

When the distance from the lens to the object focused upon is changed, there must be a corresponding change in the distance from the lens to the focal plane.

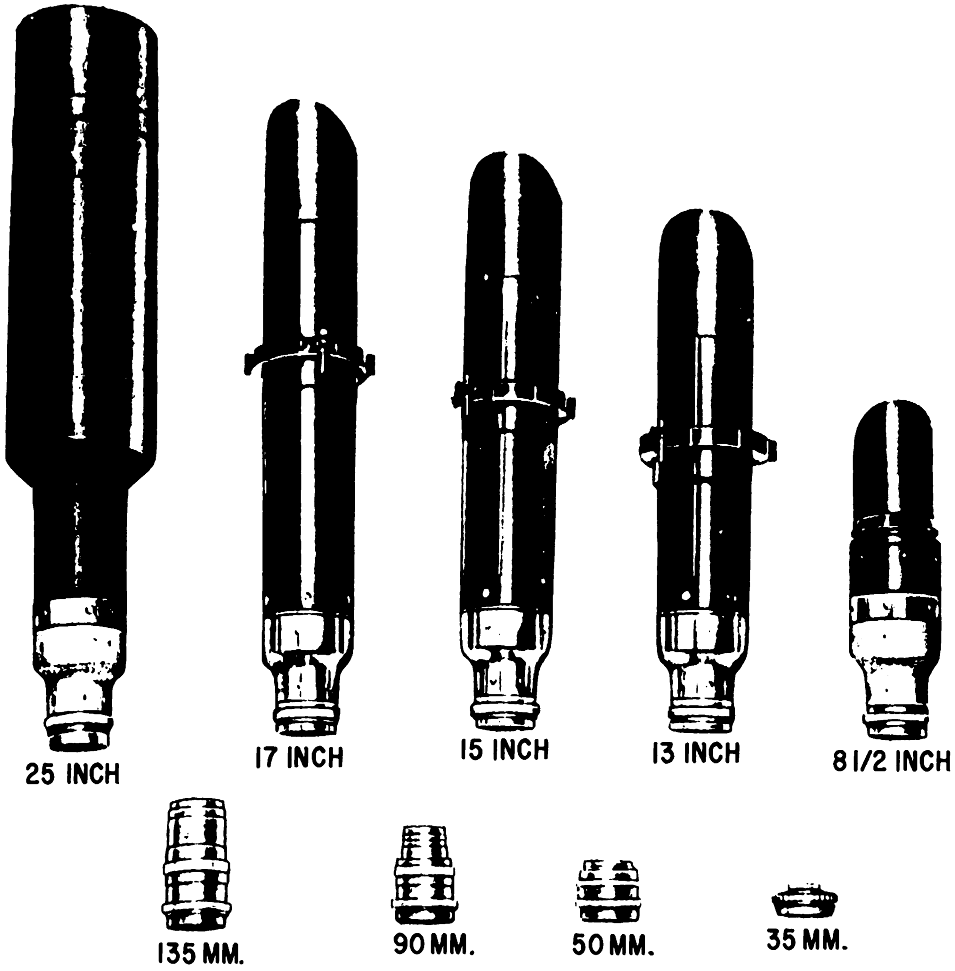


Figure 7-7.—TV camera lenses.

When the lens is focused on an object so distant that the light rays reflected from it are parallel, these rays converge, after refration by the lens, at the point of principal focus. The point of principal focus is on the principal focal plane which is at a distance of one focal length behind the lens. Therefore, the lens is said to be on infinity focus.

If this distant object is moved closer to the lens or the lens is moved closer to the object, the distance between the focal plane and the lens must be increased to keep the image sharp. When the distance between the lens and the focal plane is not extended as the object is moved closer to the lens, the image of the object becomes blurred or out of focus. Hence, as explained earlier, the size of an image formed by a lens is dependent upon two factors; the distance from the lens to the object focused upon, and the focal length of the lens.

In most types of photography it is necessary to have several objects which are at different distances in sharp focus. This means compromise because the lens cannot focus directly on several objects at different distances from the lens. If it is focused directly on a point near the lens, the distant point is not sufficiently sharp. Then again, if it is focused exactly on the far point, the near point is out of focus. The best overall sharpness for both prints can be obtained by focusing the lens a little in front of the halfway mark between the near and far points (See fig. 7-8.)

THE f-VALUE OF A LENS

To use the lens advantageously, the TD must thoroughly understand the relation between the aperture and the brightness of the image produced at the focal plane. The efforts of lens designers and manufacturers to produce lenses with high (large) relative apertures in another indication of the aperture's effect upon image brightness. The term relative aperture means the ratio between the effective aperture of the lens and its focal length.

The relative aperture of a lens is controlled by two factors: the diameter of the beam of light passed by the lens; and its focal length, which govern the size of the area over which the light is spread. Then,

$$f = \frac{F}{D}$$

Where

F = focal length

D = diameter of the effective aperture

f = f/number, or the relative aperture

EXAMPLE: What is the f/number of a lens that has a focal length of 8 inches and the diameter of the effective aperture is 2 inches? By using the formula,

$$f = \frac{F}{D}$$

$$f = \frac{8}{2}, \text{ or}$$

$$f = 4$$

Therefore, the lens has a relative aperture of f/4.

Simple arithmetic shows that the area of a circle varies as the square of its diameter. Photographically, this means that when the diameter of the opening is made smaller, less light is admitted and the image formed by the beam of light passing through the smaller opening becomes dim. Furthermore, as the size of the opening in the lens is reduced, the ratio

$$f = \frac{F}{D}$$

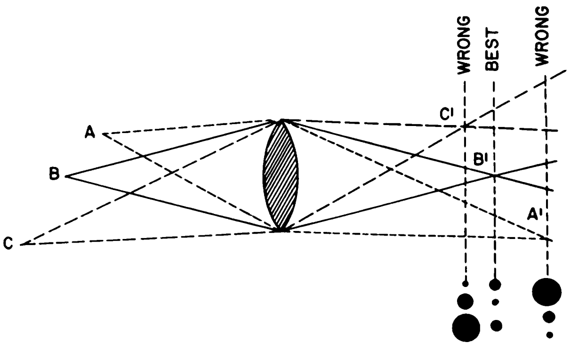


Figure 7-8.—Focusing in front of the halfway mark.

between the aperture and the focal length is increased. Then as the f/number becomes larger, the size of the relative aperture is decreased.

The focal length of the lens is the other factor which affects the brightness of the image formed upon the focal plane. Figure 7-9 depicts how this principle of the lens affects image brightness.

The strength or intensity of the light admitted by a lens varies inversely at the focal plane as the square of the distance it must travel (from the lens to the focal plane).

Since the f/number is a ratio of focal length and the lens diameter, all lenses which have the same f/numbers, regardless of focal length should give the same amount of light on the focal plane; that is, if all the other factors that affect image brightness remain constant.

THE DIAPHRAGM

There is placed in every lens assembly some mechanical device for controlling the amount of light which passes through the lens. This mechanism may have a fixed size, or it may be designed to allow a selection among a number of sizes that can be given to the aperture in a lens. This device is a diaphragm (or iris) and is frequently called stops. It is located within the lens to cut off or obstruct the marginal rays while permitting the more central rays to pass. Most lenses have a series of thin metal leaves for this purpose. These leaves are arranged and shaped to provide an approximately circular opening which can be
changed in size when desired. This devic
is used to form and control the size of th
ture or opening in the lens, is called
diaphragm. (See fig. 7-10.)

The diaphragm or iris is controll
ring or a lever by which its aperture s
be changed. By using this ring or le
index mark can be brought into line
numbers that indicate the measured
of the aperture. As these index numb
crease in size, the opening decreases
Furthermore, these numbers are so
that by moving the index pointer to t
larger number, the amount of light adm
cut in half; it should be recalled here
first or lowest number in the series is
an exception. All these numbers may
exactly within this ratio, but they are suff
close for practical purposes. However,
will find that the exact variation in all
values is in proportion to the squares
numbers. For example, f/4 admits fou
more light than f/8 because the square c
contained in the square of f/8 exactly fou

DEPTH OF FIELD

The hyperfocal distance of a lens
fined as the distance from the optical
of the lens to the nearest point in acc
sharp focus when the camera is foc
infinity at any given f/number.

Depth of field is the range of dista
the near and far side of the plane focus
within which all objects are in acc
sharp focus. When a lens is focused at

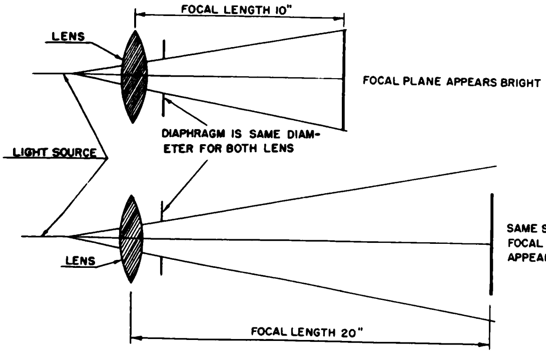

FOCAL LENGTH 10"
LENS
FOCAL PLANE APPEARS BRIGHT
DIAPHRAGM IS SAME DIAMETER FOR BOTH LENS
LIGHT SOURCE
SAME SIZE FOCAL PLANE APPEARS DIM
LENS
FOCAL LENGTH 20"

Figure 7-9.—Image brightness affected by focal length.

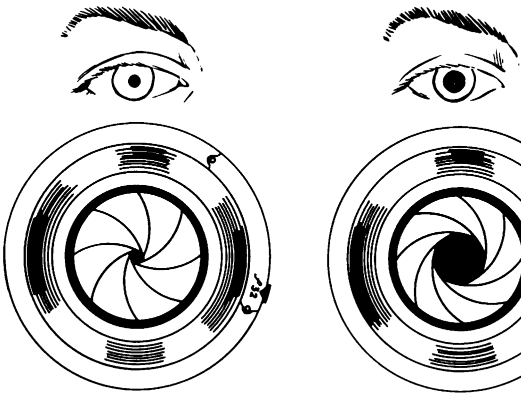


Figure 7-10.—The iris and iris diaphr

the hyperfocal distance of that lens is defined as the near limit of the depth of field, while infinity is the far distance. When the lens is focused on the hyperfocal distance, the depth of field would be from exactly half that distance to infinity. Figure 7-11 shows a typical depth of field of a lens.

The depth of field of a lens is controlled by, and all computations are based upon, the distance focused upon and the hyperfocal distance. In addition, it should be recalled that the hyperfocal distance of a lens is affected by the focal length and the f/number of the lens. Consequently, the following factors control the depth of field:

1. Focal length of the lens.
2. f/number used (the size of the diaphragm opening).
3. Distance from the lens to the object being focused.

A short focal length lens has a greater depth of field than a long focal length. Hence, the shorter the focal length of the lens used, the greater the depth of field.

Depth of field increases as the lens opening (aperture) is decreased because the size of the cones of light decreases in proportion to the aperture as shown in figure 7-12.

Physical limitations in the design of lenses, discovered in the laws of geometry, make it impossible to manufacture a lens of uniform quality and performance from its center to its edges. Therefore, to obtain the best quality with most lenses, many manufacturers recommend eliminating the use of the lens edge by decreasing the diaphragm opening about two stops from the largest aperture. This recommended stop, about two full stops below the maximum aperture for moderately fast lenses, is termed the critical aperture, or the optimum aperture. The critical aperture for a particular lens refers to the stop where the lens renders the best definition. The critical aperture for any lens may be found in the manufacturer's information pamphlet accompanying the lens or from the manufacturer.

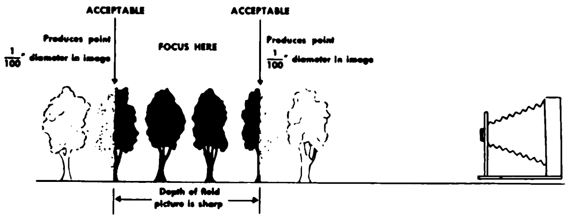


Figure 7-11.—Depth of field.

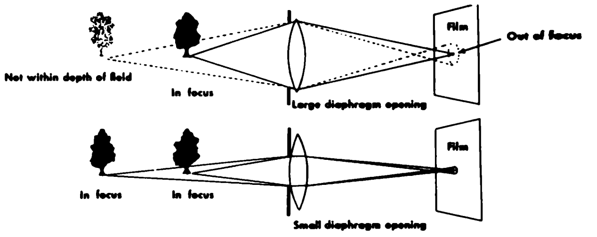


Figure 7-12.—Effect of diaphragm on depth of field.

LENS CARE

The lens is one of the most important parts of the camera unit. It is certainly an important item, since the remainder of the equipment is of little value without a lens. For this reason the lens should be given considerate and careful treatment. Severe damage to a lens can result from careless handling or improper stowage. By caring for and handling lenses as outlined in the following paragraphs, any lens should normally outlast the camera unit on which it is mounted.

The glass used in lens construction is much softer than ordinary glass. Therefore, it cannot be treated like any other piece of glass. The lens must be protected from shock, force, and compression, since any one of these will produce great differences in the internal structure of the glass.

The lens barrel should not be forced into a mount nor compressed in any other manner, because force and compression will produce changes in the internal structure of the glass.

The perspiration and natural oils from the fingers cause deterioration of the lens surface polish and dim the image. Keep the lens cap on when not using the lens. This not only protects the surface, but it also requires less cleaning of the lens.

The lens should not be subjected to chemical fumes, steam, salt spray, excessive heat, or mositure. If the lens is necessarily exposed to any one of the above, it should be given a thorough cleaning before storing.

Lenses should never be stored in spaces which are excessively warm or damp. They will remain in good condition if stored in air of average humidity at about 70 F. Furthermore, each lens should be mounted ready for use, and the storage shelves arranged to hold each lens mount vertically. As a result, each lens is supported by its own lens rings at the point where the least strain is placed on the cells.

In areas where the temperature and humidity are high, the lens should be stored in a dry locker. Each time they are removed for use, they should be cleaned and polished before being returned to the locker. They should also be inspected at regular intervals as a precaution against fungus growths.

Cleaning the Lens

Cover a table with a clean blotter or paper to prevent the possibility of damage to the lens surfaces if they should come in contact with the table. First dust the outer surfaces of the lens with a camel's-hair brush to remove the larger particles which may scratch the surface. Then spray the surface with a reco mended lens cleaning fluid, and wipe ge with lens tissue, using a circular motion light pressure.

Treat the outer surface of the other cel the same manner, and examine the assem by looking through it. Further cleaning sh not be needed.

MULTIPLEXER

To televise motion picture film, slides any prepared visual material, a specially c structed unit called an optical multiple (fig. 7-13) is used. One or more motion pict projectors are mounted on a base unit. A d type slide projector is also provided. Th projectors are aimed at a box containin system of semimirrors (a reflective sur through which light will also pass). The pic camera is aimed at the semimirrors, allov the camera to pick up and transmit pictu from any one projector or any combinatio the projectors.

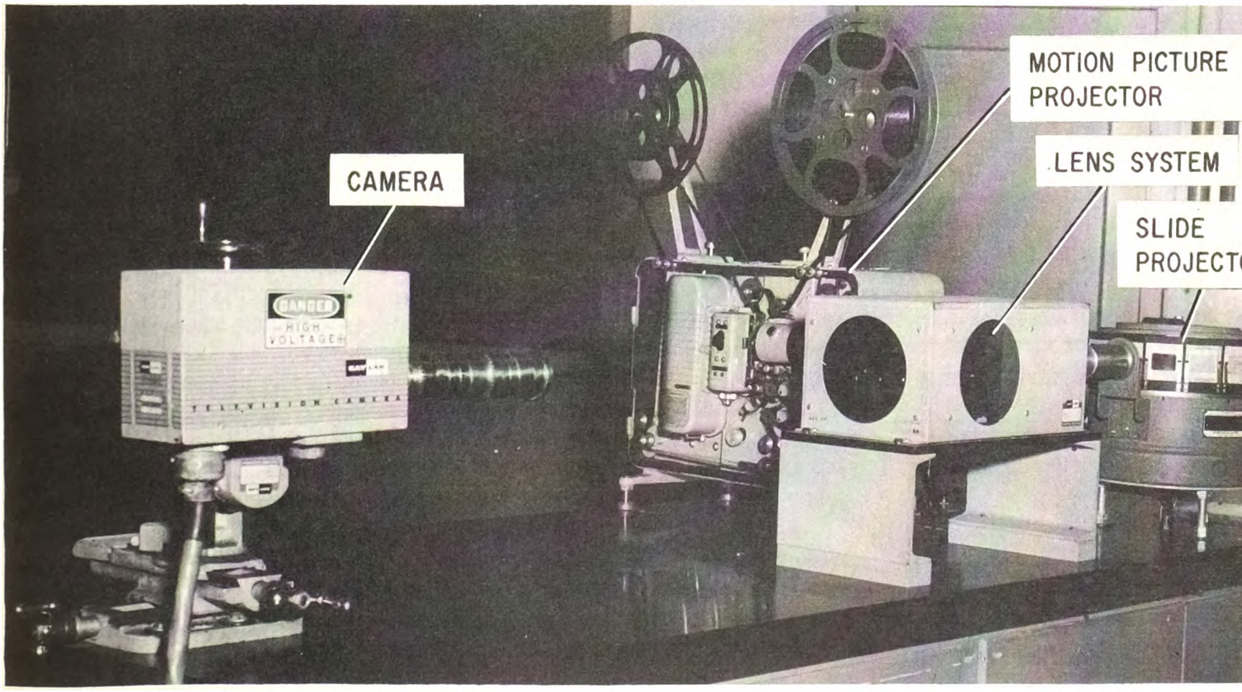


Figure 7-13.—Optical multiplexer.

A local control unit is mounted on the base unit for the operator's control of the projectors. Control of the multiplexer can be reassigned to a remote station.

The projection of the pictures from the projectors to the camera is illustrated in figure 7-14. The light rays from the slide projector (fig. 7-14 (A)) pass straight through the semimirror. The projection from the motion picture projectors (fig. 7-14 (B) and (C)) is reflected from the semimirrors to the camera.

Variac transformers, located in the base unit, control the illuminating voltage for each projector. Varying the projector lamp illumination is necessary for good reproduction.

PICKUP TUBES

The type of pickup tube used in various camera units is determined by the intended use of the camera. The amount of illumination available for the pickup tube is also a determining factor. The amount of light required by the pickup tube is rated in foot-candles (ft-c). The least number of ft-c required by the pickup tube indicates the sensitivity of the tube.

The following pickup tubes represent typical types and their uses. Other types are in use and may be encountered as one becomes familiar with the various TV systems.

ICONOSCOPE

One of the first pickup tubes developed was the iconoscope. Its present use is relatively limited to high illumination installations (multiplexer). However, its principle of operation affords a fundamental example of a pickup tube.

Figure 7-15 shows the structure of the iconoscope type of picture tube. The image of the object is formed on the mosaic by the lens system. The mosaic is composed of many thousands of tiny isolated elements, thus allowing the picture to be analyzed into a fineness of detail that is limited only by the size of the individual "islands" and by the size of the scanning electron stream.

The islands, or globules, are deposited on a sheet of mica, the back surface of which has a continuous metallic coating. Thus, each globule is capacitively coupled to the continuous metallic coating which serves as the signal electrode. When a scene is focused on the mosaic, the globules emit photoelectrons and become electrically charged by an amount proportional to the brightness of the picture elements. As the linescanning electron stream comes along, the electrons, having a velocity generated by approximately 1,000 volts, strike these globules and discharge them to an equilibrium voltage. The basis of operation is due to secondary emitted electrons caused by bombardment of the mosaic by the high velocity electron beam. The collector ring collects the secondary electrons (the number is determined by the relative charges on the mosaic) and provides a path through the developing resistor to the metallic plate. The electron flow through R is indicative of the light intensity variations focused on the mosaic.

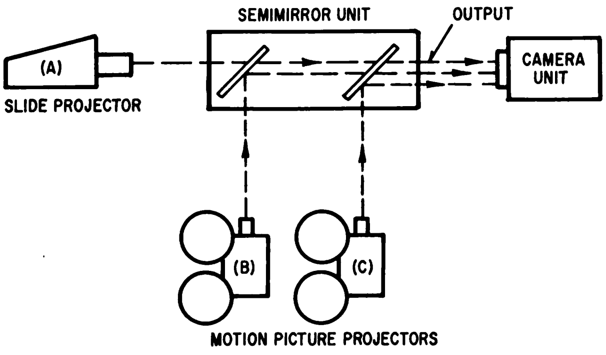


Figure 7-14.—Block diagram of a multiplexer.

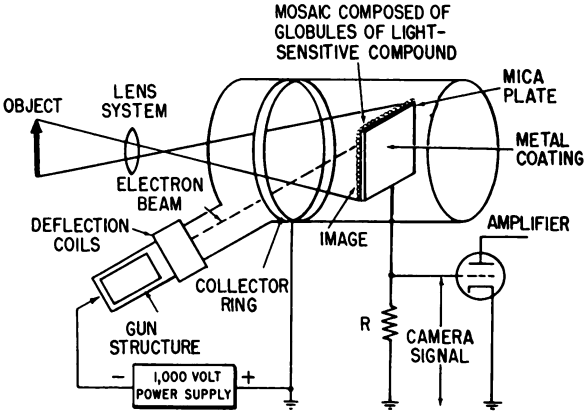


Figure 7-15.—Structure of an iconoscope.

The amount of discharge is proportional to the accumulated charge stored up since the previous electron scan. The discharge of the globules is capacitively coupled to the continuous metallic backplate. In this way the scanning beam produces a series of electrical signals from the globules in the mosaic, and one collecting electrode furnishes a connecting point for the lead to the video amplifier.

The signal from the collecting electrode is about 1 millivolt, and its frequency components may vary from 30 cps to as high as several megacycles per second.

The iconoscope picture tube requires 800 ft-c of light and is now mostly limited to motion picture pickup work found in multiplexer equipment. In this tube, both the scene to be transmitted and the electron stream are projected onto the same side of the photosensitive surface. Because the electron stream has an accelerating voltage of approximately 1,000 volts, considerable energy is present in the beam and much of the performance of the iconoscope depends upon secondary emission in charging and discharging the globules on the mosaic.

VIDICON TUBE

The Vidicon camera pickup tube (fig. 7-16) has a transparent conductive coating, called the signal electrode, on the inner surface of the faceplate; a layer of photoconductive material deposited on the signal electrode; an accelerating electrode; a focusing electrode; and a cathode emitter for producing a beam of electrons.

The beam of electrons is directed toward the layer of photoconductive material (on the cathode side of the signal electrode) at a medium velocity because of the relatively low acclerating potential between the cathode and the accelerating electrode. A sharp beam is formed by the electrostatic field of the focus electrode and the axial magnetic field of the focus coil surrounding the tube. The electron beam is deflected by the deflection coil in such a way as to scan the photoconductive layer. When no light is permitted to reach this layer, its resistivity is extremely high. One side of the layer is maintained at cathode potential through contact with the scanning beam, and the other side is maintained at a small positive potential of 0 to 70 volts by direct contact with the signal electrode.

When light from the scene being tel
passes through the faceplate and is fo
onto the photoconductive layer, the resis
of this material (which had been extr
high) is reduced in proportion to the a
of light reaching it. Because the pot
gradient between adjacent elements of the
conductive layer is much less than the pot
gradient between opposite sides of the
electrons from the beam side of the
leak by conduction to the other side be
scans of the electron beam. Consequentl
potential of each element on the beam
approaches the potential of the signal ele
side and reaches a value that varies wi
amount of light falling on the element.
next scan, the electron stream replaces a nu
of electrons on each element just suffici
return it to the potential of the cathode
cause each element is effectively a small
citor, a capacitive current is produced
signal-electrode circuit that corresponds
electrons deposited as the element is sca
When these electrons flow through the
resistor in the signal-electrode circuit, a
age, which becomes the video signal, is proc

Associated with the Vidicon tube ar
alinement coil, the focus coil, and the defl
coils. The alinement coil produces a ma
field that is variable in both magnitud
direction and is used to adjust the dir
of the electron beam so that it is para
the field of the focus coil. Control of the
ment coil current is accomplished in the c
unit.

The focus coil surrounds the Vidicon
and establishes a magnetic field along th
of the tube. It is connected between the +30
and the +150-volt power supplies thro
resistor that is located in the rotatable s
of the base unit.

The vertical and horizontal deflection
are excited by linear sawtooth currents
the control unit. These currents produc
field that causes the beam to scan the
sensitive layer.

IMAGE ORTHICON

The image orthicon (fig. 7-17) is an
sensitive television camera pickup tube
tube requires only 8 to 40 ft-c of ligh
is used in modern conventional and
circuit television systems. When this tu
used, a light image from the subject (ar

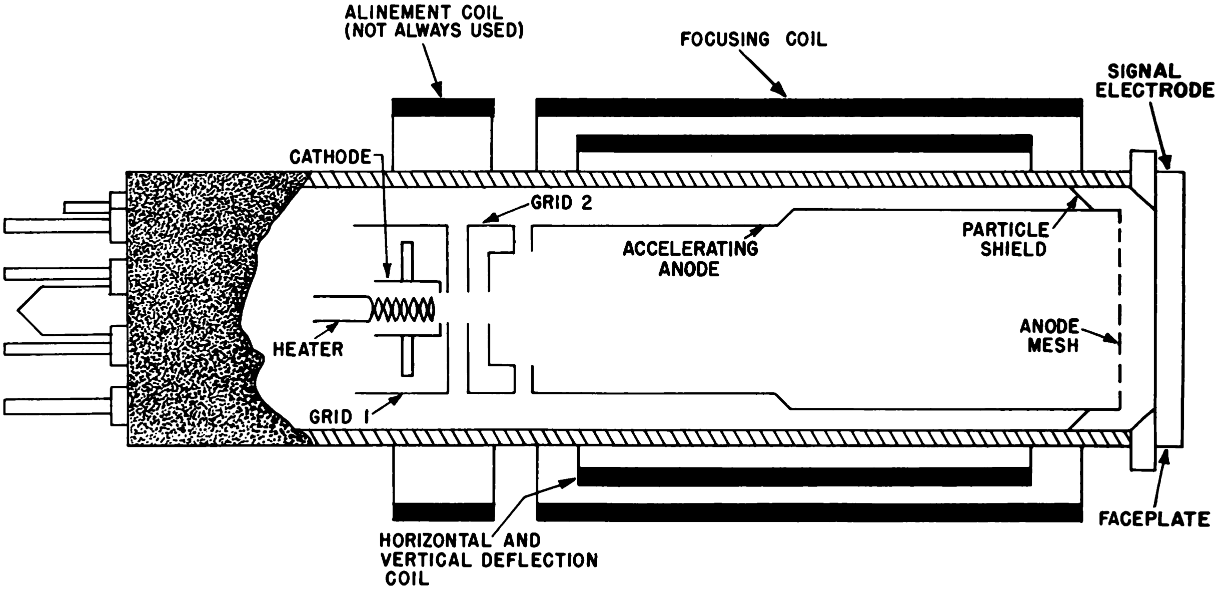


Figure 7-16.—Structure of Vidicon tube.

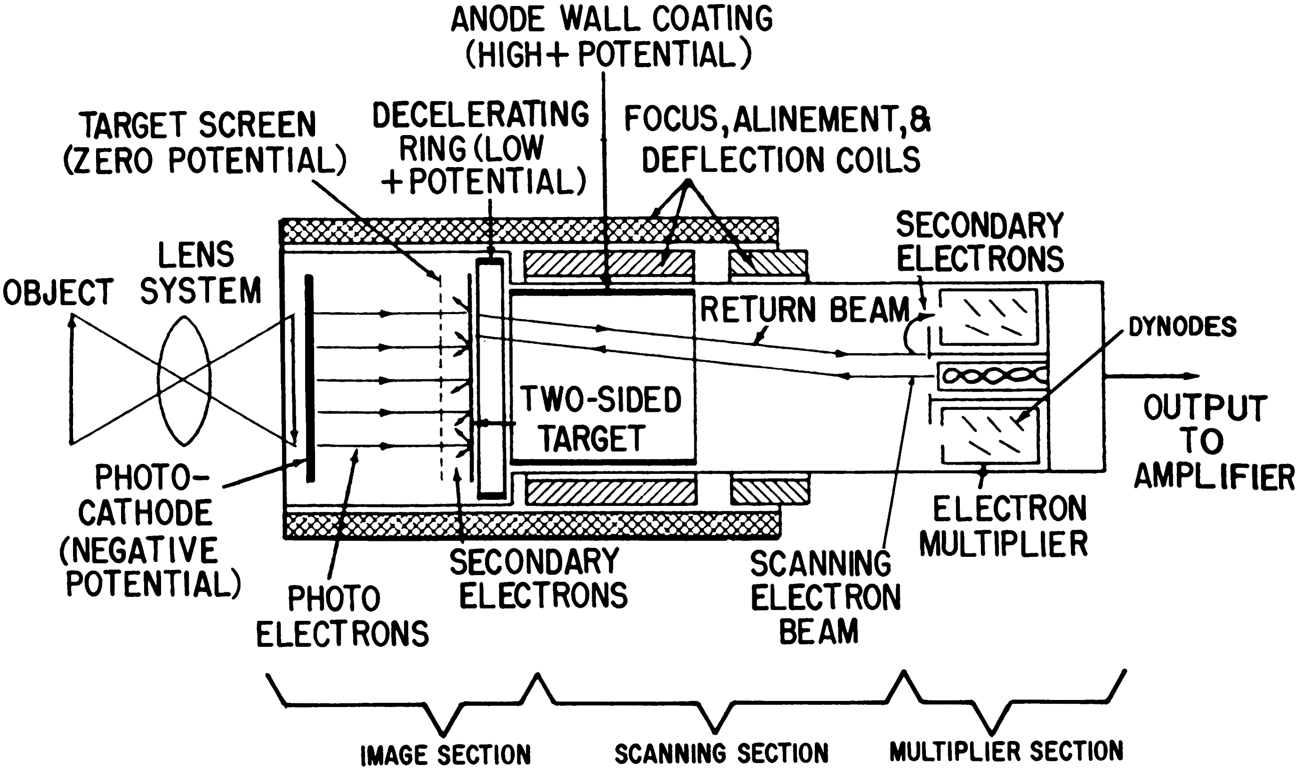


Figure 7-17.—Structure of image orthicon.

extreme left) is picked up by the camera lens and focused on the light-sensitive face of the tube, releasing electrons from each of the thousands of tiny globules in proportion to the intensity of the light striking it.

These electrons are directed on parallel courses from the back of the tube face to the target, from which each striking electron liberates several more electrons, leaving a pattern of proportionate positive charges on the front of the target. When the back of the target is scanned by the beam from the electron gun in the base of the tube, enough electrons are deposited at each point to neutralize the positive charges, the rest of the beam returning, as shown in figure 7-17, to a series of electron multiplier stages or dynodes, surrounding the gun.

Each dynode is a metallic disk with openings similar to a pinwheel and operates at a positive potential of 200 to 300 volts greater than the preceding dynode. Multiplication occurs through secondary emission at each dynode. If five dynode stages are employed, each with a gain of 4, then (4 x 4 x 4 x 4 x 4) a gain of approximately 1,000 is realized in the multiplier section. Considering the gain of 5 in the image section, the overall gain of the image orthicon is 5,000 which allows this particular pickup tube to operate with relatively less light than the iconoscope or vidicon. The electrons from the last dynode are routed through a signal developing resistor to an extremely high B plus voltage. The output signal is then coupled to the first stage of video amplification.

OTHER CAMERA TUBES

The "image dissector" is another type of television camera tube in common use. In such a tube, the scene is focused upon a continuous photosensitive surface (such as a film), and the resulting photoemission is focused as a pattern by suitable focusing fields and accelerated toward a small collecting aperture. The whole photoelectric pattern of streaming electrons is then deflected in a scanning process, so that individual areas of the picture are successively brought to impinge upon the small aperture. The electron stream collected in this manner is amplified by several stages of electron multipliers using secondary emission. The output of the multipliers is then fed to a video amplifier.

Another type of scene scanning (camera) tube is called a "flying spot" scanner. (See the 15Z4 and 5 described in Tradevman 3 & 2, NavPers 10376-A.) This scanner is used to project slides or still pictures.

The complete scanner (fig. 7-18) requires the following units:

1. A standard sync generator.
2. A sweep unit for deflecting the electronic beam of a cathode-ray tube with a short persistence phosphor (ordinary picture tube).
3. Optical means for imaging the raster on variable density or opaque subject matter.
4. A multiplier type photocell to collect either the transmitted or reflected light and represent the variable density or variable reflection as an instantaneous voltage variation with time.
5. Suitable mixing circuits to provide composite video output. The raster traced out on the short persistence screen results in a moving light source which is the basis of the whole operation.

Because the decay time of the moving point source of light is relatively long compared to the period of the highest frequency components desired in the video signal, special peaking circuits (to be described later) must be used. The multiplier type photocell produces a high level output signal with good signal-to-noise ratio. In order to get high resolution (good detail) in the video output signal, the low frequency components in the output must be attenuated considerably to bring up the high frequency components. This may be accomplished with selective amplifiers, with RC networks, or with RL networks.

When a slide is to be transmitted, the raster traced out on the cathode-ray tube is imaged optically on the slide to be reproduced. Condenser lenses are used past this focal plane to collect the maximum light energy passing through the slide, and to converge this energy to the aperture dimensions of the multiplier photocell.

BASIC CAMERA CIRCUITS

The purpose of camera amplifier circuits is to amplify the extremely low output signal from the pickup tube. The video signals must be increased in amplitude to overcome tube and circuit noises. Random circuit noise and hum will impose itself into the video output.

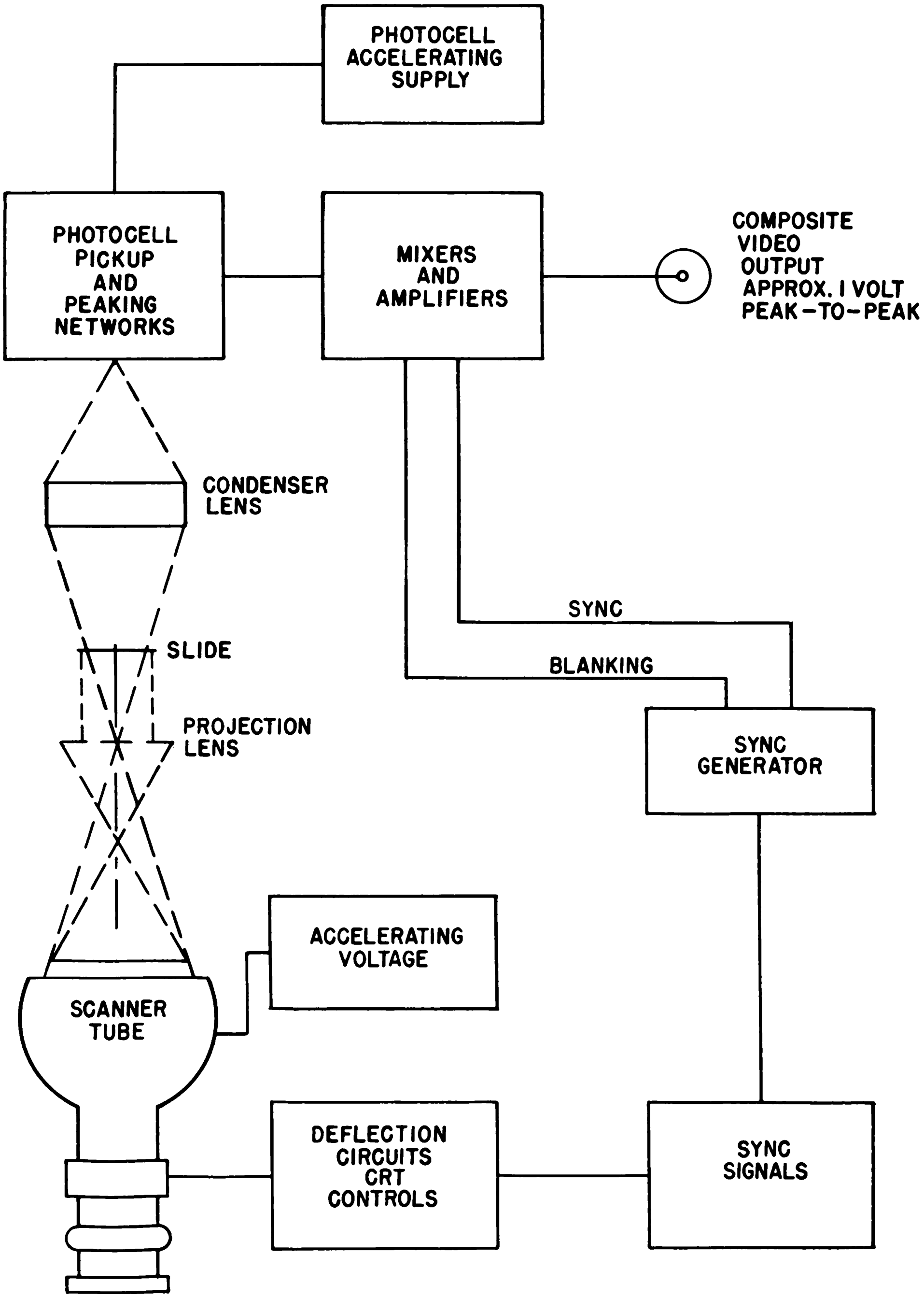

PHOTOCELL ACCELERATING SUPPLY
PHOTOCELL PICKUP AND PEAKING NETWORKS
MIXERS AND AMPLIFIERS
COMPOSITE VIDEO OUTPUT APPROX. I VOLT PEAK-TO-PEAK
CONDENSER LENS
SLIDE
PROJECTION LENS
SYNC
BLANKING
SYNC GENERATOR
ACCELERATING VOLTAGE
SCANNER TUBE
DEFLECTION CIRCUITS CRT CONTROLS
SYNC SIGNALS

Figure 7-18.—Slide scanner using flying spot scanner cathode-ray tube.

The camera circuits are carefully designed to amplify the high and low frequencies equally. The output of the pickup tube (fig. 7-19) must be as large as possible. The output circuit contains high resistance which gives good gain to low frequencies, but low gain to high frequencies. Because video signals contain both frequencies, stages of amplification are designed to amplify one frequency more than other frequencies.

The video amplifier (V1) amplifies the video signal from the pickup tube. The low frequencies are amplified more than the high frequencies. (Note waveforms showing frequency response of each block.) V2 is part of a "peaker" circuit whose function is to amplify the high frequencies, while the video amplifier (V3) amplifies all frequencies. The video signal, having been amplified, is routed through a cathode-follower amplifier (V4). V4 is used to match the impedances of the camera unit to the control unit via coaxial cables.

The camera unit (fig. 7-20) of the X8F1 CCTV system provides an example of camera unit circuits. The detailed descriptions of individual circuits are contained in Basic Electronics, NavPers 10087-A.

V1 is the schematic presentation of the Vidicon pickup tube. Like the common schematic presentation of electronic tubes, the tube elements of V1 are electronically the same; however, the terminology employed differs somewhat. The filaments of the tube require filament voltage and current. The control grid is referred to as the beam control, while the plate is called the target control.

The video signal leaves the pickup tube (V1) on pin C of the tube. A variable d-c focusing voltage is applied to pin 6 of V1 via the decoupling network R5 and C4. A fixed positive accelerating voltage is applied to pin 5 of V1 through R42 and the contacts of K1, from pin 16 of J1. K1 is normally closed when operating. A variable beam control bi: vertical blanking pulses are applied to of V1 from pin 15 of J1. A pulse derive the horizontal deflection yoke through S1 in normal position) is differentiated and R3, clipped by CR1 and R4, and a to the cathode of V1 as a sharp p horizontal blanking pulse.

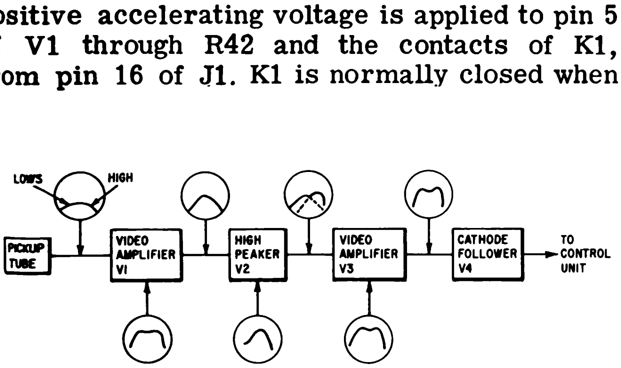


Figure 7-19.—Camera unit block diagram.

The synchronized video output, taken fr C of V1, is fed to V2 and V3, which ar nected as cascode amplifiers (a grou cathode input stage feeding a grounde second stage). The input signal appears control grids of V2. The voltage divider ne for the output tube V3 is R11, R13, R1 R15. The output signal from the plat V3 travels through series and shunt p by L2 and R14, L1 and R16, with deco by R15 and C9. From there the sign coupled through C10 to the control grid

V4A is a cathode-follower circuit wi cathode resistor (R201) for the circuit l in the camera control unit. The cathode re develops the video signal in the camera c unit from the camera unit. Location cathode resistor in the camera contro reduces signal loss normally associated long connecting cables. Switches S1 a reverse the connections to the horizonta vertical deflection yokes, changing the p from left to right and upside down, respect This allows the operator to check the cent of the deflection circuits.

Relay K1 is a protective switch fo pickup tube. If either the horizontal o vertical deflection signals fail, V5 wi conduct, allowing K1 to open. Thus, th celeration voltage is removed from pin 5 A portion of the vertical deflection sign routed through C14 to the control grid of The amplified signal coupled through C rectified by CR2 and applied as positive to the control grid of V5. Similarly, a from pin 8 of J1 passes through C13, is rec by CR3, and is applied as positive bias suppressor grid of V5. K1 is in the circuit of V5; and as long as plate cu flows, the relay stays energized. If the voltage on either pin 1 or pin 7 of removed, the tube will stop conducting, ca K1 to deenergize. When K1 is deener voltage is removed from pin 5 ov V1, an grid is grounded through R41. This c protects the target screen from burnin to the scanning electron beam stopping.

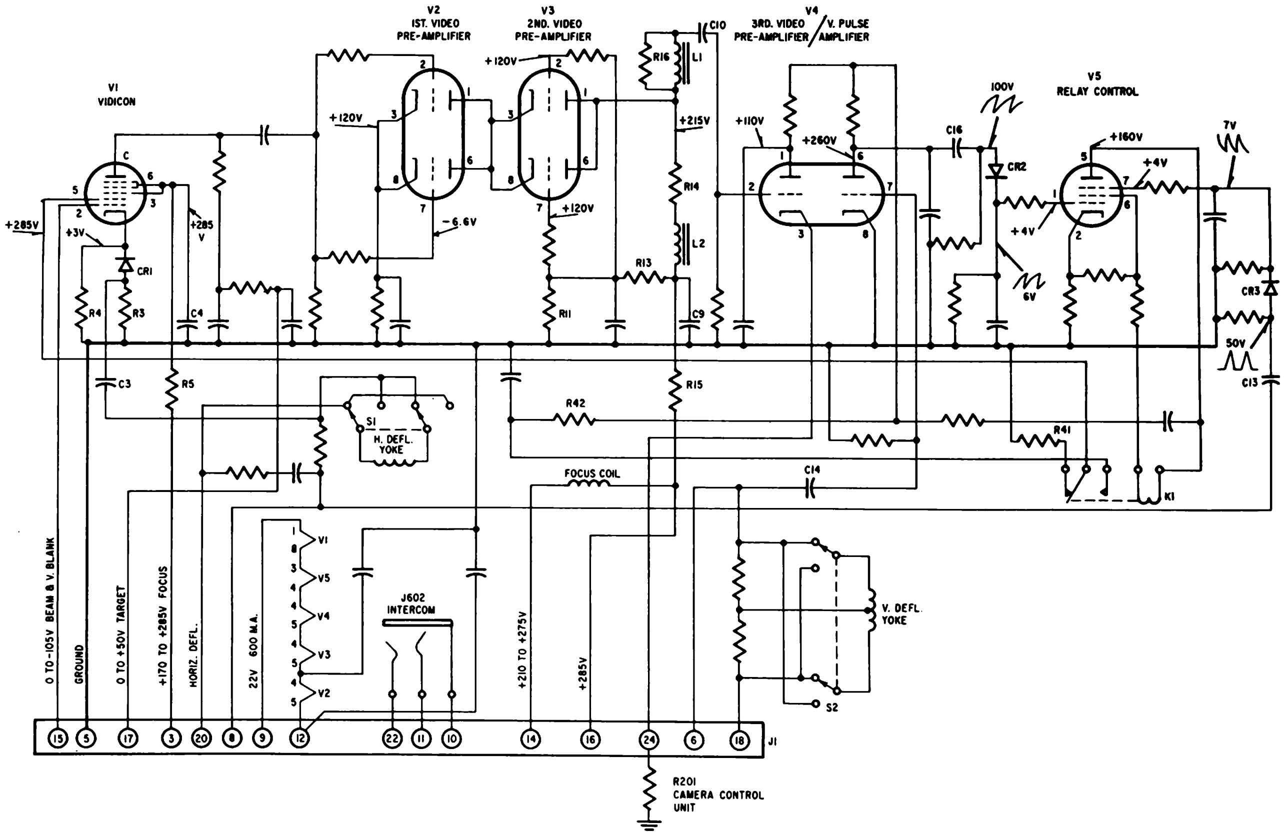


Figure 7-20.—Camera unit, device X8F1.

COMPOSITE VIDEO

The composite video signal contains all the information needed to reproduce the picture. Included is the video from the camera unit, synchronizing pulses to synchronize the transmitted signal with the receiver/monitor, and blanking pulses to obliterate the retrace signals from the picture tube. The video signal is combined with the blanking pulse (fig. 7-21); the sync pulse is placed on top of the blanking pulse.

In the composite video signal, successive values of voltage and current amplitudes are shown against values of time during the scanning of three horizontal lines. During the time when blanking and sync pulses are being transmitted, no video is appearing. The overall signal amplitude is divided into two parts: the lower 75 percent is for the video, and the upper 25 percent is devoted to synchronizing pulses. Standardization is necessary to insure that the transmitted signal is suitable for all receivers/monitors.

The lowest amplitudes correspond to the whitest parts of the picture. The picture becomes blacker as amplitude increases toward 75 percent. This standard of transmission is called "negative transmission," which is defined as decreasing signal amplitude for decreasing light intensities. As the level reaches 75 percent, the grid cuts off the picture tube and the absence of light establishes the blackest level, which is the case when the blanking level occurs.

Details of the horizontal blanking and sync pulse are shown in figure 7-22. The interval of the complete scan is 63.5 microseconds since horizontal frequency is 15,750 cps. The horizontal blanking pulse is 10.16 microseconds,

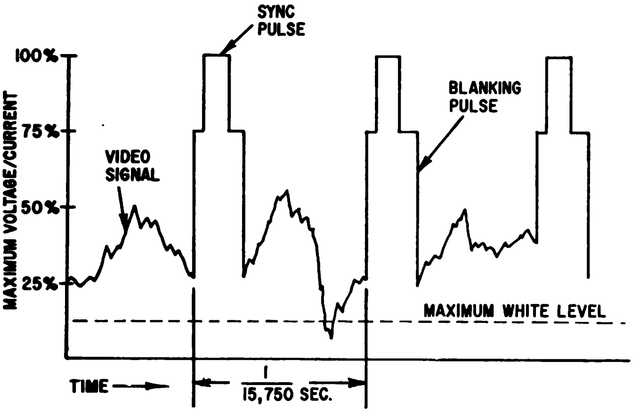


Figure 7-21.—Composite video signal.

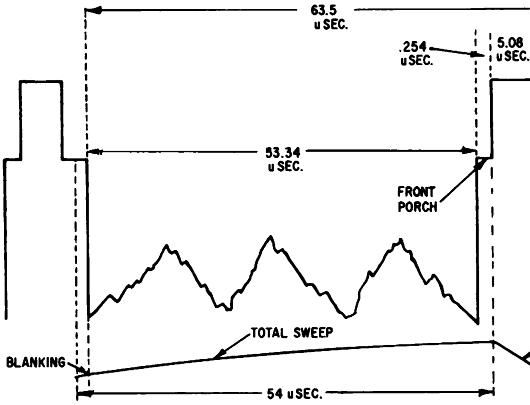


Figure 7-22.—Composite video tim allocations.

or about 16 percent of total sweep. The sync pulse, superimposed on the pedestal, occupies 5.08 microseconds or one-half the blanking time.

The part of the pedestal just before the sync pulse (0.254 microsecond) is called the "front porch"; the portion following the sync pulse (4.826 microseconds) is called the "back porch." The front porch blanks the right side of the picture screen just before the sync pulse begins. Flyback occurs with the leading edge of the sync pulse and continues for 4.42 microseconds of the back porch. The next sweep starts, but the left side of the screen is blanked for 0.406 microsecond of the starting sweep. This action strives to maintain a straight left edge.

The vertical blanking pulse blanks the picture during retrace time when the electron beam has completed one field and is returned to the top ready to start the next field. Immediately following the last active line, the video signal is brought up to the black level by the vertical blanking pulse in preparation for the vertical retrace.

So far in the discussion little has been said about the special form of the combined synchronizing pulses. The form and the timing of the synchronizing pulses are such that the horizontal and vertical oscillators are triggered at exactly the right instant to keep the sweep in the camera tube and the sweep in the picture tube locked in step. Because the horizontal oscillator must be triggered during the vertical sync pulse (to prevent the horizontal oscillator from drifting out of control), the vertical pulse is serrated, as shown in figur That is, the vertical pulse is chopped pieces. The fluctuations resulting fro rations do not affect the operation vertical oscillator, but serve only to k horizontal oscillator properly triggered.

In addition to the serrations in the pulse, equalizing pulses are necessary and after each vertical pulse. The ne for the equalizing pulses, labeled E ir 7-23 (B), may be explained as follows:

First, it is assumed that no equalizin are used, as in figure 7-23 (A). If the pulse is inserted at the end of the fiel occurs simultaneously with the end o horizontal line (part (1)), the firing p of the vertical oscillator is reached correct time to produce the desired int scan.

If the vertical pulse is inserted at of a field, which occurs simultaneously end of a half horizontal line (part (firing potential of the vertical oscill reached too early. This results from t that the slight charge on the capacitor triggering circuit of the vertical oscillat to each horizontal pulse) does not hav to leak off before the vertical pulse a The residual voltage across this capacit the voltage due to the vertical pulse, the vertical oscillator to fire too soon.

Second, the situation is corrected, as in figure 7-23 (B), by the use of equ pulses. The buildup of the vertical pulse

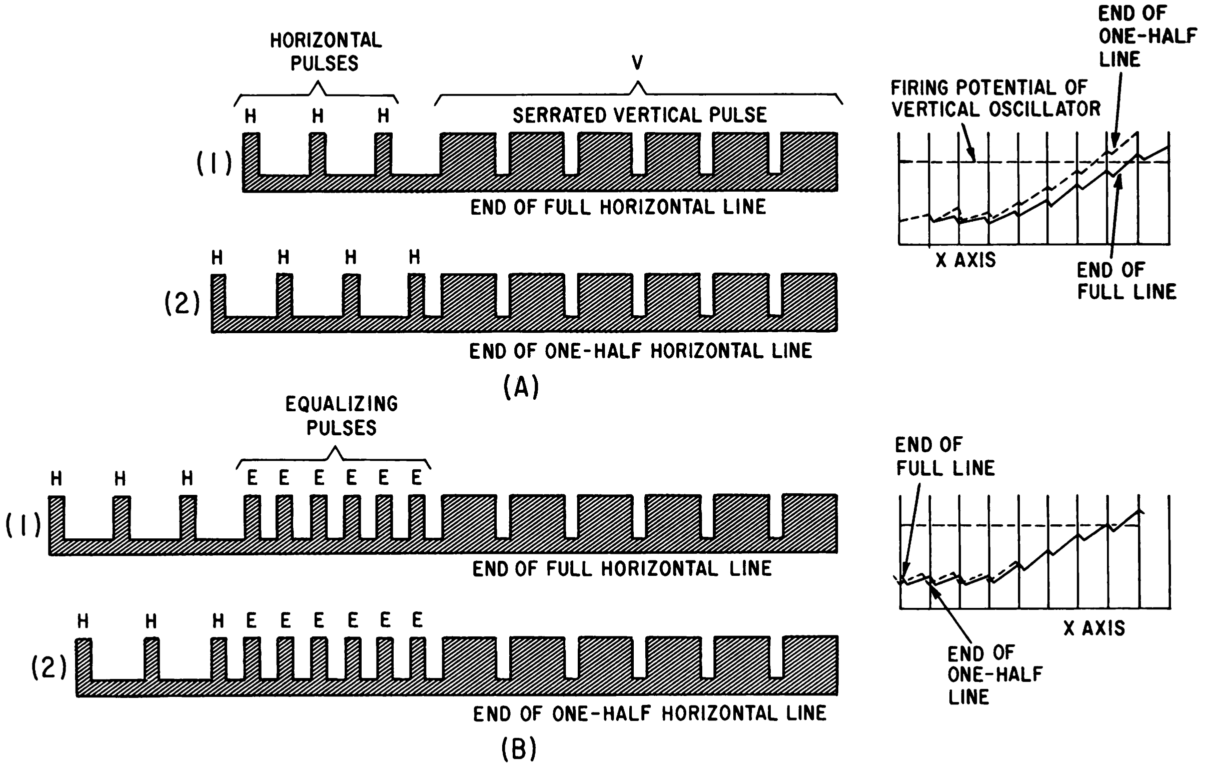


Figure 7-23.—Synchronizing pulse forms. (A) Without equalizing pulses; (B) with equalizing pulses.

the capacitor now begins at the same point regardless of whether the vertical pulse arrives at the end of a full line or at the end of a half line. In other words, the equalizing pulses cause the potential on the capacitor to be at the same level (at the same time the vertical pulse arrives) regardless of whether the vertical pulse occurs at the end of a half line or at the end of a full line. Although not shown in the figure, equalizing pulses are also used after the vertical pulses.

A better idea of the form of sync pulses may be obtained from a study of figure 7-24. It may be seen that a number of horizontal scans are lost during the vertical flyback time.

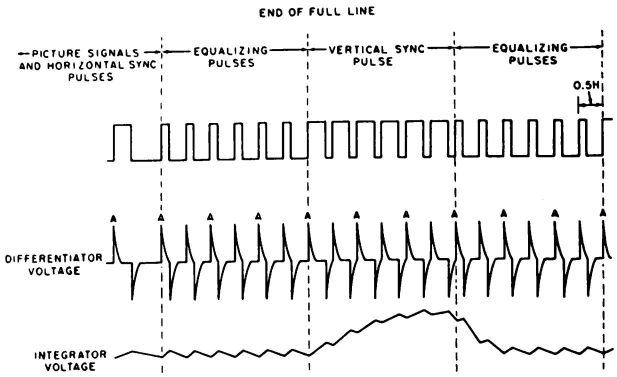


Figure 7-24.—Form of sync pulses showing the output integrator and differentiator voltages.

CONTROL UNIT

The sync pulse generator is located in the control unit of the CCTV system, device X8F1 (fig. 7-25). The purpose of the master oscillator (sync pulse generator) is to generate the basic oscillating signal which provides the vertical and horizontal blanking pulses and the sync pulses.

The output of the master oscillator sends a 31.5 kc signal to the phantastron counter circuit where the vertical frequency of 60 cps is developed. A 15,750 cps output is also sent to the horizontal counter and sweep circuits.

Outputs from the horizontal and vertical sweep circuits are sent to the camera unit for synchronizing the pickup tube. Both vertical and horizontal pulses are routed to the blanking mixer circuit where the combined pulses are sent to the composite video mixer. Video from the camera unit and the sync pulses a and leave the control unit as the c video signal.

A schematic diagram is included block contained in figure 7-25. When the individual circuit diagrams, refer 7-25 to maintain overall continuity of the

SYNC GENERATORS

The master oscillator circuits (f develop the timing signals for the enti system.

V401A and its associated compone pose a single swing blocking oscilla oscillating frequency of 31.5 kc (fun frequency) is determined by the RC C418, R450, and R447. At the same tank circuit consisting of C416 and L4 lates at 94.5 kc. With these two

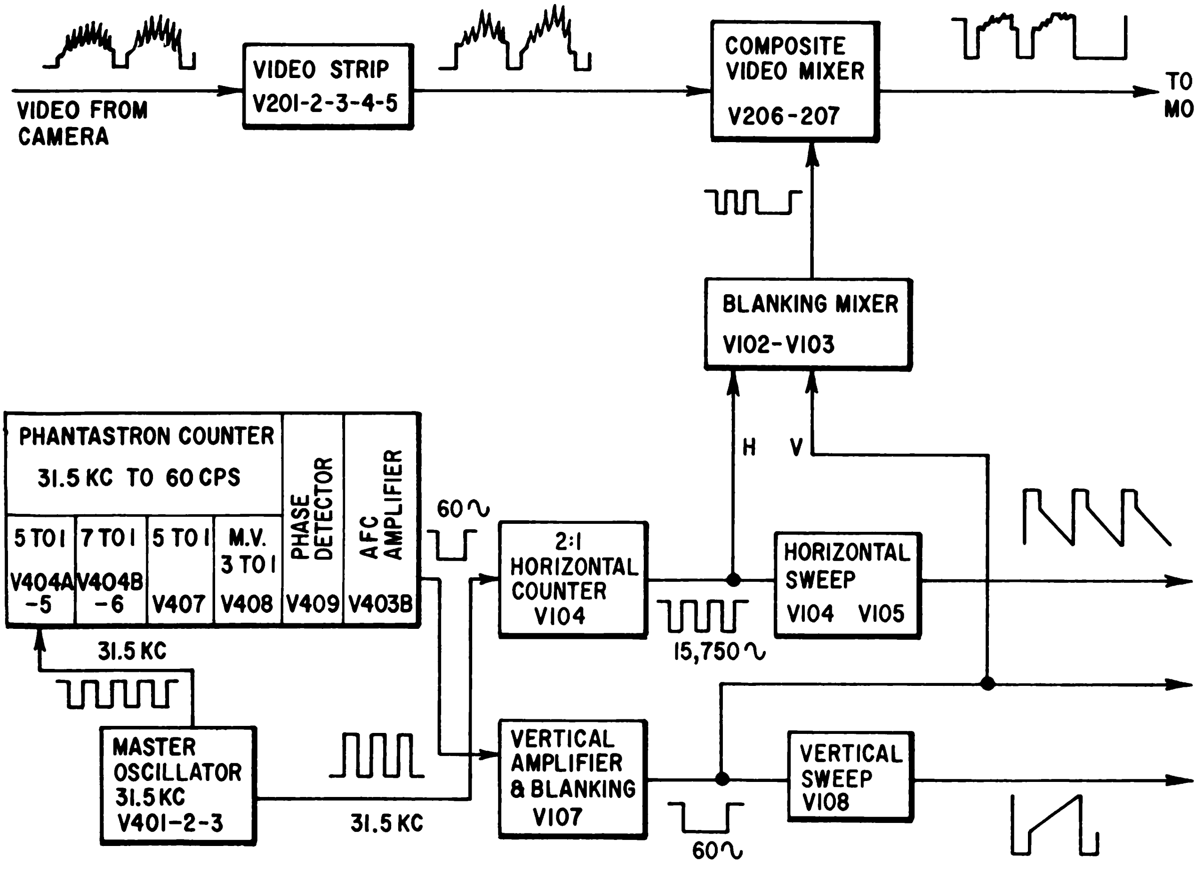


Figure 7-25.—Control unit, device X8F1.

oscillating at the same time, the fundamental frequency (with the stabilizing signal superimposed on it at 94.5 kc) appears on the control grid of V401A. The output signal from the cathode of V401A is fed to TP405, a test point where the output of the oscillator can be checked.

From TP405 the signal has two paths to follow: First, one through C420 to the grid of V402A; and second, one through C419 to the grid of V401B. V401B is a buffer amplifier used to separate oscillating stages. The output (31.5 kc pulses) leaving the plate of V401B goes to the phantastron counter circuits. (See fig. 7-25.)

The other signal from TP405 (coupled through C420) goes to the grid of the multivibrator V402A (fig. 7-26). The time constant of the circuitry components is designed to trigger on every other pulse received from V401A. Thus with a 31.5-kc input, the output is 15,750 cps. Assuming that V402A is cut off, V402B is conducting. A positive spike from V401A brings V402A out of cutoff. Increasing the plate current of V402A causes an increase in voltage drop across R460, which is reflected on the cathode of V402B. The rise in cathode potential causes an increased bias on V402B which decreases conduction. This decrease is amplified by the discharge of C421 through R462, driving the grid further negative. This action continues until V402B goes to cutoff.

V402A continues conducting with V402B cut off until C420 discharges at an exponential rate to allow V402B to start conduction again. V402A conducts five times as long as V402B and results in a pulse output which is horizontal blanking.

The plate output of V402B is a square wave varying around a positive potential. The signal is coupled throuch C422 and applied to the grid of V403A and CR401. CR401 is a clamper, limiting the positive square wave and clamping the negative pulses at zero.

The output of the cathode follower (V403A) is a negative-going waveform which is routed to pin 3 of J102 which in turn is connected to the horizontal sweep circuits. (See fig. 7-25.)

COUNTER CIRCUITS

The vertical countdown circuits (fig. 7-27) consist of a series of counter circuits which divide the frequency of the resulting pulses by 5, 7, 5, and 3 to produce ultimately the 60-cps vertical drive pulse.

The 31.5-kc signal from V401, the master oscillator, comes into the circuit through C402 to the cathode of V404A. the phantastron tube (V405) is designed so that the control grid controls tube current and the suppressor grid controls plate current only.

By reviewing the static voltages indicated on V404A and V405, the static condition of V405 can be determined. Plate current is cut off by the suppressor grid of V405. Screen grid current is maximum, causing 35 volts to be present at the cathode. The control grid is also at a potential of 35 volts. With no plate current flowing, the voltage at pin 5 (V405) and pin 2 (V404A) is approximately 175 volts. The voltage divider formed by R409 and R410 places 170 volts on the cathode of V404A. At this time V404A is conducting and plate current at V405 is at cutoff. However, screen grid current of V405 is at maximum.

A negative pulse appears on the cathode of V404A and drives the cathode negative in respect to the plate. V404A conducts harder, sending the effect of the spike through C401 to the control grid (pin 1) of V405. The negative-going control grid of V405 reduces screen grid current and cathode voltage. As the cathode voltage goes below 19 volts, the suppressor grid allows plate current to flow, reducing the plate voltage below 170 volts. As the plate voltage decreases toward 20 volts (see waveform at pin 5 of V405), C401 cannot change instantaneously. C401-discharges at its reactance rate through R402, R401, the power supply, R406, and V405. This discharge path forms an extremely long RC time constant. As this discharge time is occurring the control grid voltage slowly rises. The cathode voltage also rises, increasing the bias between the cathode and suppressor grid. The bias continues to increase until plate current ceases and screen grid current again takes control.

During the discharge time of C401, four more pulses appear at the cathode of V404A, but have no effect on V405. Thus, the cathode of V405 will react to one input pulse for five incoming pulses. The output frequency has changed from an incoming frequency of 31.5 kc to 6.3 kc, a division of five. Notice that the waveform at TP401 shows a decreased pulse every fifth position, indicating that one pulse out of five is affected by the sequencing of the phantastron V405.

The output from the cathode of V405 is coupled through C403 to the cathode of V404B.

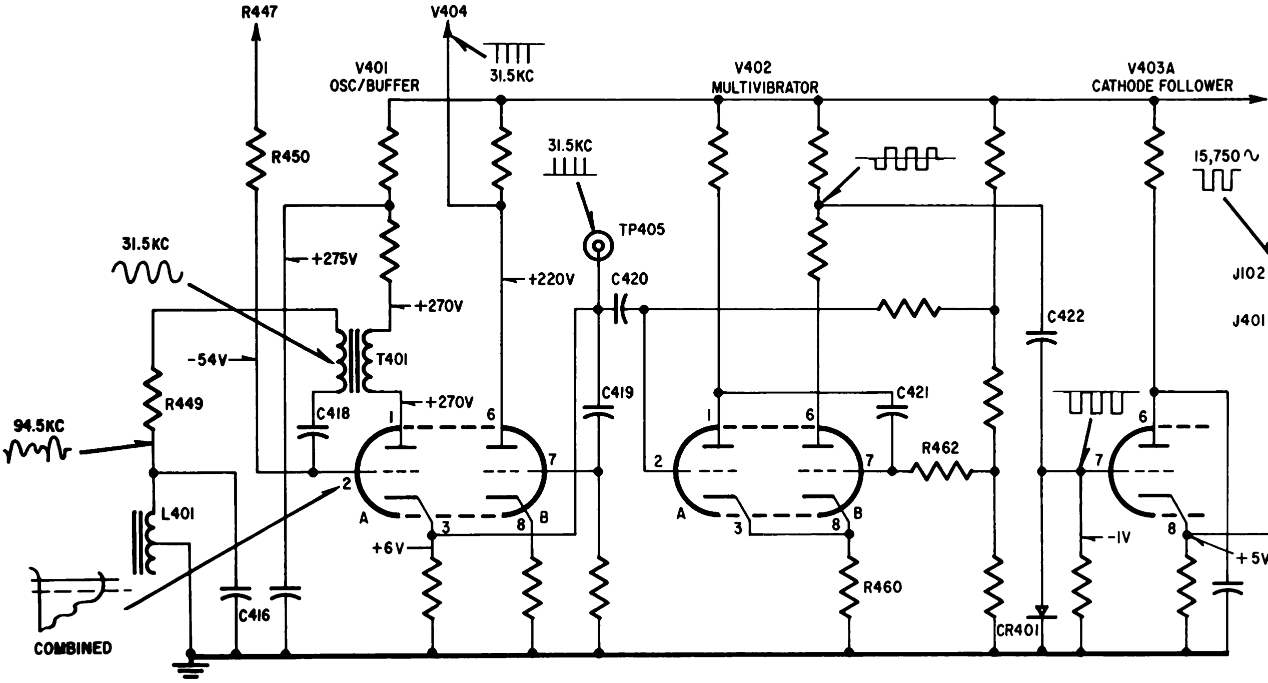


Figure 7-26.—Oscillator circuit, device X8F1.

V404B operates the same as V404A by shuttling the 6.3-kc pulse signal to the control grid of V406, the seven-to-one phantastron. The size of C404 is such that V406 pulses once for every seven input pulses. The frequency changes from 6300 cps to 900 cps, a division of seven.

The cathode output of V406 is coupled via C405 to the cathode of V404C. V404C and V407 comprise a five-to-one phantastron and produce an output of 180 cps.

The cathode output from V407 is differentiated by C407 and R432, and is coupled to the grid of V408A by C408. V408 is a cathode-coupled multivibrator. It is timed to cycle on every third input pulse which produces an output frequency of 60 cps. The output signal from the plate of V408B is routed via R437 through C410 to J401. This supplies the vertical frequency for the vertical blanking and sweep circuits.

A positive-going 60-cycle pulse is coupled from the cathodes of V408 to coupling capacitor C409. A negative-going 60-cycle pulse is coupled from the plate of V408B to coupling capacitor C412. V409 is a phase detector used to synchronize the master oscillator with a cycle line frequency to eliminate "line cra as a result of 60-cycle pickup in the vari circuits. It also maintains a fixed ratio betw the 60-cycle vertical signal and the 15,750 generated by the master oscillator. This act results in a good stable interlaced scann raster. With a positive signal at the bottom R442 and a negative signal at the top of R44 60-cycle sine wave is injected through R to the center point of R442 and R441.

With the AFC (automatic frequency cont switch, S201, in the "lock" position, freque stabilization is maintained. If the phase of positive pulse tends to lag behind the 60-cy sine wave, the conduction of the diode V40 increases. If the negative pulse applied to cathode of V409A tends to lead, conduction V409A also increases. A positive d-c volt is present at the output of the phase detec if the pulse tends to lag. A negative d-c volt is present if the pulse tends to lead. In eit case, the voltage is directly imposed at grid of V403B, controlling plate current. conduction of V403B is through R447 wh

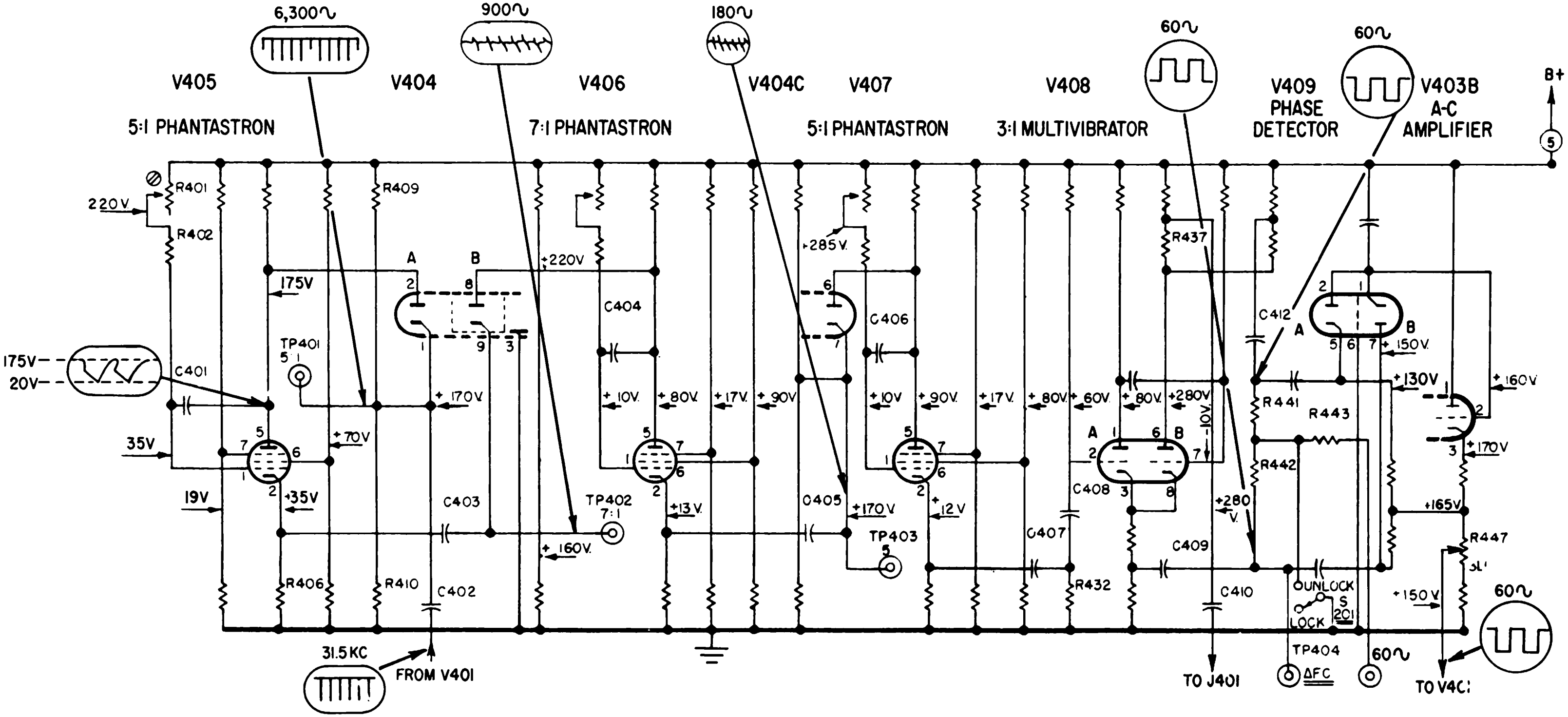


Figure 7-27.—Vertical countdown circuits.

wiper arm is connected to the control grid of the 31.5-kc master oscillator. Thus, if the control grid of V401 (master oscillator) is made less positive, C418 (fig. 7-26) now has a new discharge reference. Cutoff time of V401 increases, therefore, the output frequency decreases in proportion to the amount of d-c voltage feedback from V403B. The opposite would occur for an increase in positive voltage at the grid of V401.

Switch S201 is placed in the "unlock" position when adjustments are to be made to the phantastron counting circuits. When S201 is "unlocked," a ground is placed at the tie point of R441 and R442. This allows the shifting of the counter circuits for frequency adjustments.

SWEEP AND BLANKING GENERATORS

The sweep and blanking generators along with the blanking mixer (fig. 7-25) develop the timing signals for the scanning of the pickup tube and the blanking pulses to blank the receiver/monitor picture screen.

In the device X8F1, sync pulses for the receiver/monitor are clipped and separated from the blanking pulses (25 percent of the blanking pulses are employed for synchronization). Some systems have sync pulses (shorter duration) riding on top of the blanking pulses; all systems require some form of synchronization pulses for retrace action.

The circuits of the vertical and horizontal sweep and blanking generators are shown in figure 7-28.

The vertical negative pulses enter the circuit at pin 4 of J102 and are coupled through C128 to the grid of V107A. V107A amplifies and inverts the signal which is coupled from the plate of V107A through C133 to the grid of V108A. Here the pulse is formed into a trapezoidal pulse for a constant rise in current which is necessary in the inductive output circuit. The pulse is again shaped by C135 and R153 and coupled through C134 to the vertical output amplifier (V108B). The positive voltage towards which C135 charges can be varied by the "vertical size" control R148. This varies the amplitude of the trapezoidal pulse. The operating point and the sawtooth current are coupled from the plate of V108B through the top lead of T102 to the "centering" control R141. From R141 the sawtooth is routed to pin 18 of J402 via pin 7 of J102. From T102 the other lead (bottom) goes to pin 6 of J and then to pin 6 of J402.

The driven horizontal circuit receives a 750 cps negative square pulse from the s generators. This pulse is applied to pin 3 J102, and is coupled through C116 to control grid of V104A. The pulse is ampli by V104A and V105A and used to discha C120, which in conjunction with R133 fo the horizontal trapezoidal pulse. The puls further amplified by V105B and V106. Pu amplitude is adjusted by R128, pulse shap controlled by R129, and centering is determi by R140. The output transformer T101 cou the sweep pulse through pins 1 and 2 of J to pins 20 and 8 of junction block J402.

The negative horizontal drive pulse, pres at pin 3 of J102, is routed to the control g of V101A via C102. In V101A the pulse amplified and coupled as a positive pulse thro C103 to the grid of V101B. V101B, a paraph amplifier, produces two pulses of oppo polarity through the coupling capacitors C and C105 to connector pins P1 and P2. Th pulses are used in the video amplifier establish a reference level for the video sign

The horizontal drive pulse applied to 3 of J102 is also routed to the grid of V1 via C107. V102 is the horizontal blanking a plifier which amplifies the pulse and app it as a positive pulse to the cathode of V1 via C109. The negative vertical pulse at plate of V107B is coupled to the control gri V103A via C106.

The horizontal and vertical pulses are co bined and amplified by V103A and applie the grid of V103B via C113 and CR101. R R122, and CR101 form a wave shaping netw which straightens the leading edges of pulses. The output of the sync amplifier (V10 is shaped by C114 and R123 and coupled to 7 of J101 by C137. The blanking outpu routed to the video amplifier where it combined with the raw video from the cam circuit and produces composite video.

VIDEO TRANSMISSION CIRCUITS

The video amplifier (fig. 7-29) cont the circuits for amplifying the raw video f the camera unit and inserting the blan and clamping pulses. (See the block diagr fig. 7-25.)

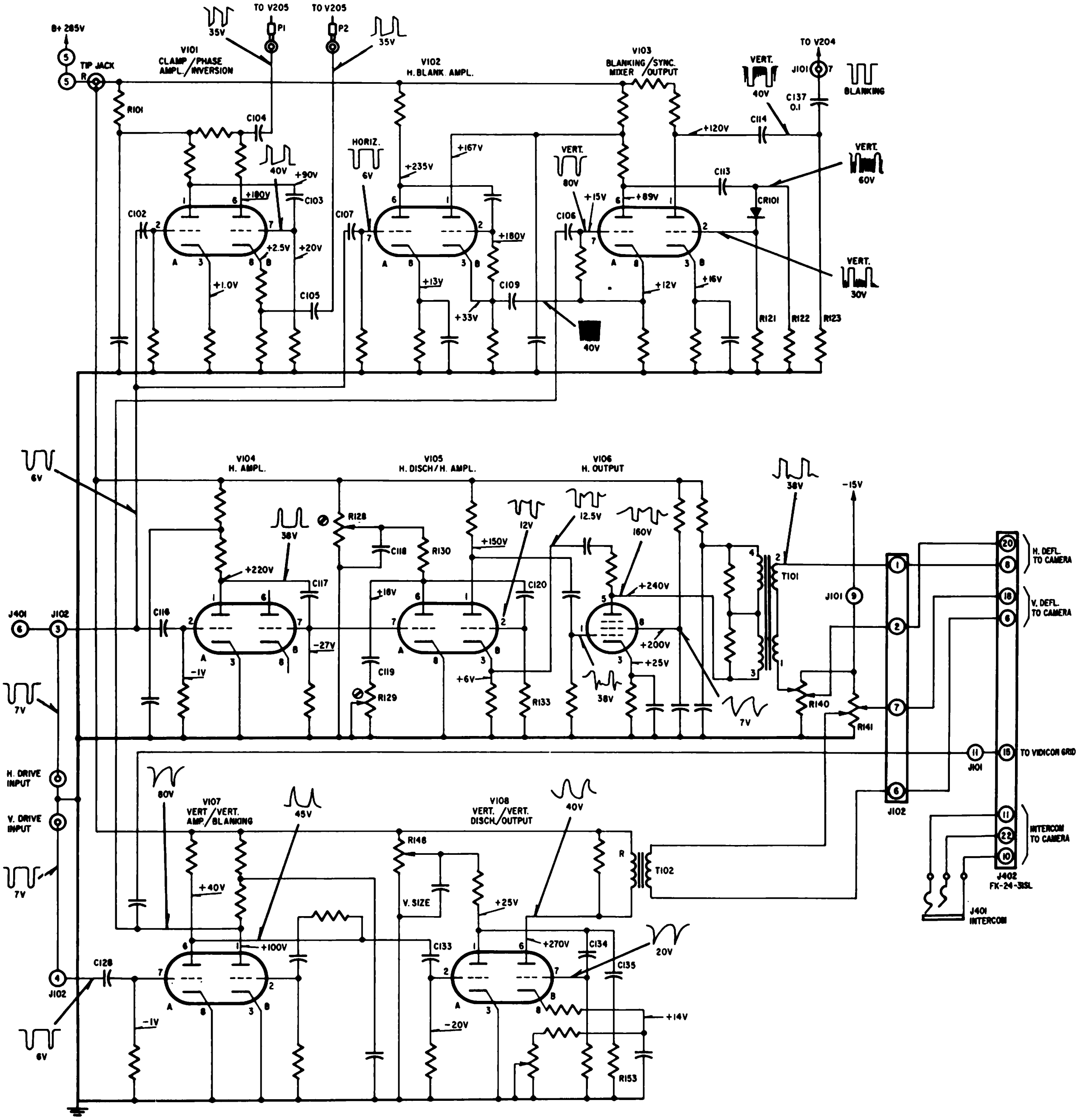


Figure 7-28.—Sweep and blanking generators.

The raw video from the camera unit is connected to the video input jack (fig. 7-29) and is coupled through C201 to the grid of V201A. The amplitude, or gain, of the video is varied by R1406 which varies the bias of V201. V201A and V201B are connected as

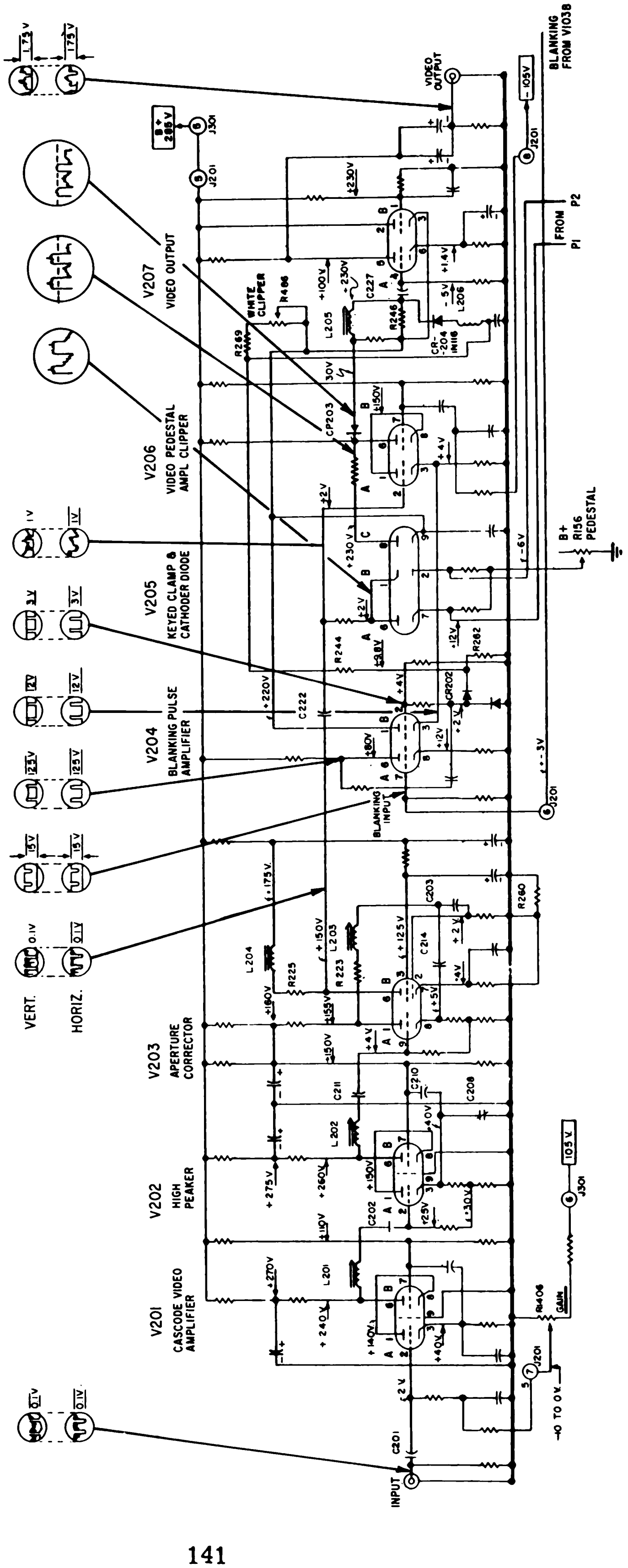


Figure 7-29.—Video amplifier, device X8F1.

a cascode amplifier (a circuit having the gain of a pentode and the low noise level of a triode).

The plate output of V201B goes through L201 and is coupled by C202 to the grid of V202A. V202 is another cascode amplifier with adjustable peaking by C208.

The output from the plate of V202B goes through L202 and C211 to the grid of V203. Aperture distortion results when the electron beam in the pickup tube is too large to individually sweep each particle of the photosensitive plate. The splashing effect results in a very small amount of loss in resolution. The loss occurs in the high frequencies of the video. V203 operating as an aperture corrector, attempts to exaggerate the amplification of the high frequencies while at the same time amplifying the low frequencies. The amplified video from the plate of V203A goes through R223 and L203 (shifts signal phase to lead the lagging effect of C214) to the junction of C203 and C214. C214 offers a low impedance return to the cathode of V203A for high frequencies. They are again amplified. All frequencies are coupled through C203 to pin 2 of V203B. The output from V203B is developed across R225, peaked by L204, and is coupled through C222 to the grid of V206A.

The blanking pulse from the blanking mixer circuit (fig. 7-25) comes into the circuit (fig. 7-29) through pin 6 of J201 to the control grid of V204A. V204A amplifies the pulse and the output from the plate goes to the grid of V204B. CR201 and CR202 clamp the voltage at a positive 2 volts d.c. The pulse is amplified at V204B and the signal goes from pin 3 of V204B to pin 3 of V206.

The negative and positive pulses at P1 and P2 are coming from the clamper V101 (fig. 7-28). These pulses are routed to the cathodes of V205A and V205B (fig. 7-29). V205 is called a "keyed clamper." The "keyed clamper" restores the d-c reference level of the video to insure the constant reference to the "black level." The reference level is adjusted by R156.

The pulses on the cathodes of V205 are equal in amplitude and 180° out of phase. When the video, which is coupled through C222, appears at the plates of V205, the conduction of either or both diodes maintains the video at a constant reference point. R156 is adjusted so that the reference voltage is a positive 2 volts.

The blanking pulse from the cathode of V204B also appears on the cathode of V206A. The control grid of V206A receives the raw video from C222. If sync pulses were needed, they would also be inserted at this point. The combined signals are amplified in V206A and coupled to the cathode of V206B. The relatively large blanking pulse is amplified along with the weak raw video. The output waveform at the plates of V206 which appears to be exaggerated is limited, or clipped, by CR203 which brings the ratio of the blanking pulse down as compared with the video. (See the waveforms on each side of CR203.) The purpose of the pedestal clipper, CR203, is to clip the upper portion of the sync (if included) and blanking pulses to produce a clean square pedestal. The composite video signal from CR203 goes to the grid of V207A via L205 and C227.

The purpose of V205C is to prevent the inverse voltage rating of CR203 from being exceeded and also to assist CR203 in its clipping action. The plate is normally negative with respect to the cathode. If the inverse voltage attempts to increase, the diode will conduct, lowering the cathode voltage of CR203.

The purpose of the "white clipper," R486, is to reduce the amplitude of the excessive video white signals in order that the lower level background information is not destroyed. V207B, R486, R269, R244, and R262 form a voltage divider from B+ to ground. The potential at the wiper of R486 is applied through R246 to the cathode of CR204. The potential existing between R269 and R244 is applied through L206 to the anode of CR204. The potential across CR204 is therefore controlled by the position of R486. It is adjusted for 1 volt reverse bias on CR204.

The video signal appears at the tie point of CR204 and C227. If the white video signals go negative enough to overcome the reverse bias of 1 volt, CR204 will conduct. This limits the negative-going swing of the video.

The output composite video from the plate of V207A is coupled through C230 to the video output jack. A cable from the output jack connects the control amplifier video system to the video system in the receiver/monitor (fig. 7-30).

The composite video supplied the monitor video circuit is coupled through C101 to the control grid of the video amplifier (V101). Low frequency compensation is achieved by C102

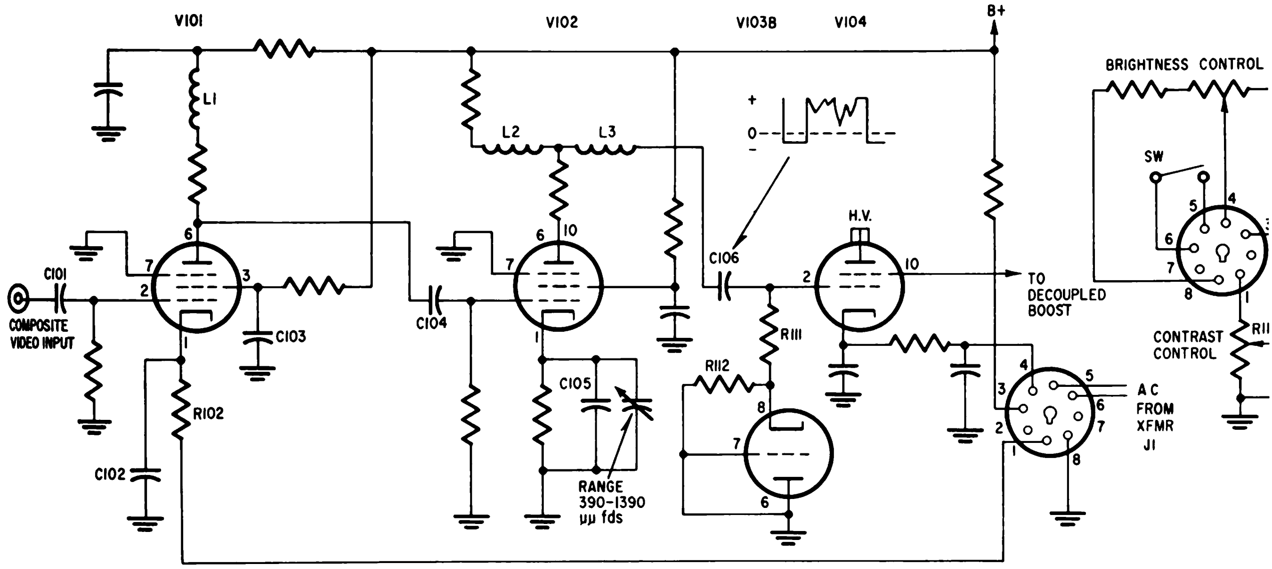


Figure 7-30.—Monitor, video section, device X8F1.

and C103, while L1 serves as a shunt peaking coil for high frequency compensation. The contrast control (R117), which is connected to the cathode of V101 through R102 and J1, varies the gain of the video amplifier.

The output of V101 is coupled through C104 to the control grid of the video amplifier (V102). L2 is a shunt peaking coil, and L3 is a series peaking coil. C105 is a variable adjustment for low frequency compensation.

L3 and C106 couple the output of V102 to V103B and to the control grid of the picture tube (V104). V103B is called a d-c restorer which establishes a stable reference level for the fluctuating signal ready to be placed on the picture tube. The circuit evaluates the incoming signals and establishes the average of all the pulses as a reference. The large negative pulses cause V103B to conduct heavily, and its conduction path allows a short discharge time for C106. The short discharging path through R111 and V103B causes R111 to develop a small negative voltage. When C106 starts to charge, its only path is through R112 and R111 and therefore appears as a long RC time in relation to the path for a negative-going signal.

All incoming signals are referenced in respect to the potential across R111 to ground. The action maintains a stable video signal for the picture tube.

The high voltages at pin 10 and the cap V104 are supplied from the deflection and hig voltage power supply which is described in th following chapter.

POWER SUPPLY

The power supply for the control unit als supplies the operating voltages for the camer unit. The power supply is a standard heavy-dut full-wave rectifier system with electroni regulation.

LINE AMPLIFIER

When the camera unit or the receiver monitor unit is located at a distant point fro the control unit, a booster called a line amplifier is used. When additional receiver/monitor units are desired, the line amplifier provides additional signal levels.

Input composite video signals are connecte to the video input jacks J1 and J2 (fig. 7-31 When only one input cable is to be used, 75-ohm resistor is connected from the othe input jack to ground, providing the prope impedance termination for the cable in us The input cable, from the control unit connected to J1, can be continued to another lin

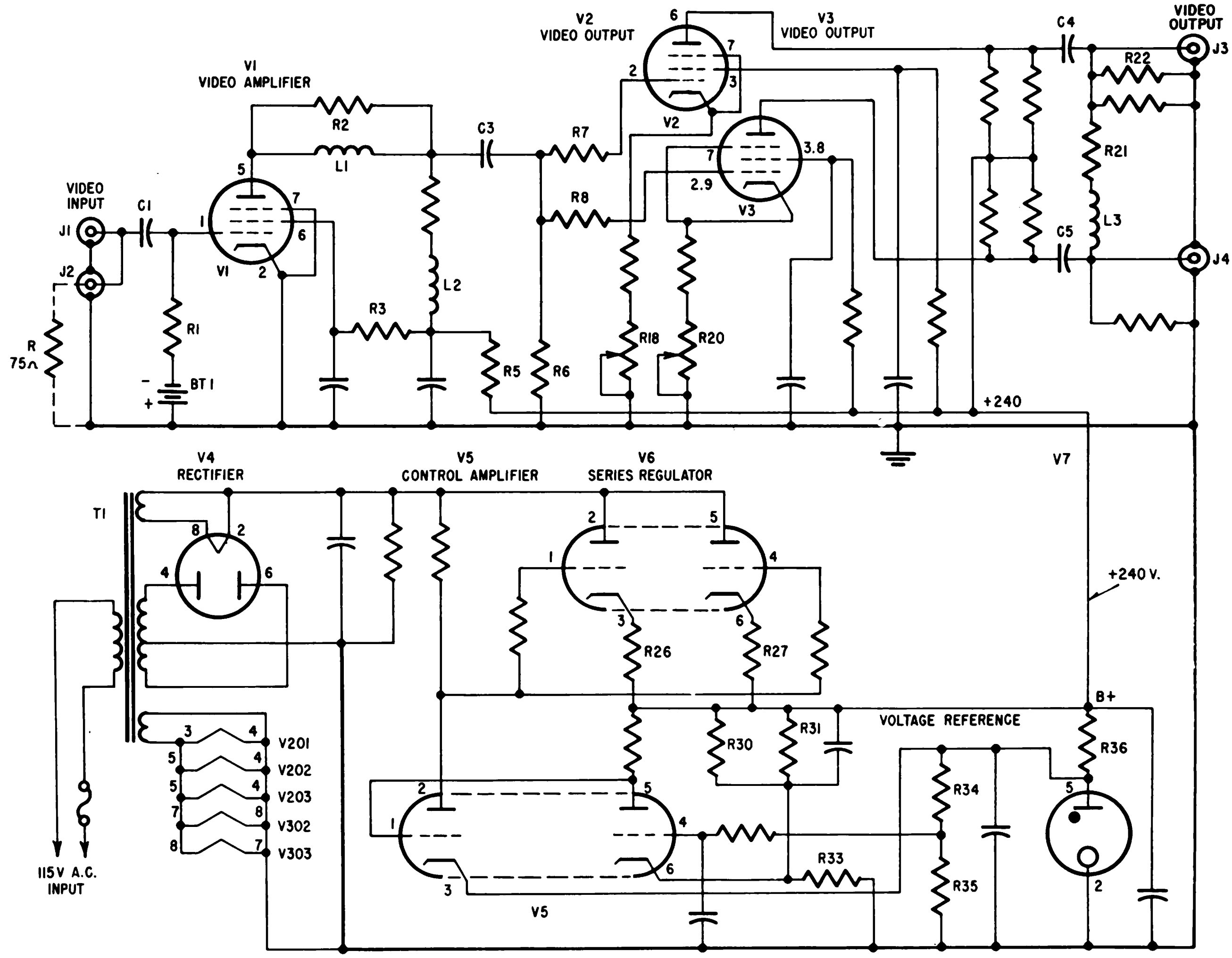


Figure 7-31.—Line amplifier, device X8F1.

amplifier by connecting another cable to J2 and on to another line amplifier or monitor.

The input signal is coupled through C1 to the control grid of V1. Fixed negative bias is placed on V1 by BT1. BT1 contains two mercury bias cells producing 2.7 volts d.c. The fixed bias is used to increase the low frequency response by allowing the cathode of V1 to be grounded. The screen grid of V1 is connected to B+ via R3 and R5. The output from the plate of V1 is routed through L1 and R2, and is developed across shunt peaker L2. The coupling capacitor C3 routes the signal through R7 to the control grid of V2, and through R8 to the control grid of V3.

Resistor R6 serves as the grid leak resistance for both V2 and V3. Resistors R7 and R8 are grid limiting resistors to prevent the control grids from drawing current. Gain controls R18 and R20 vary the outputs of V2 and V3, respectively. Parallel outputs are coupled across C4 and C5 with high frequency peaking by L3 and R22 to output jacks J3 and J4.

The power supply provides the filament and B+ voltages required by the amplifier circuits. The circuit is a full-wave rectifier with electronic regulation.

The regulator tube maintains a fixed potential on the plate of V7, across R34 and R35, and on pins 3 and 4 of V5. The regulated B+ voltage is present at the top of R36. If the B+ voltage should decrease, the decrease would be present along the line at the top of R36. Since R31, R30, and R33 form a voltage divider network, a proportional part of the decreased voltage is present at the connecting point of R31 and R33. This point is also connected to the cathode of V5B. This decreasing voltage at the cathode of V5B causes its plate current to increase. The increased plate current causes the plate voltage to drop, which is reflected (direct coupled) on the grid of V5A. The lower grid voltage causes an increase in the plate voltage of V5A which also controls the grid voltage of both V6A and V6B. This change in control grid voltage causes an increase in plate current of V6. The increased plate current flows through R33, R30, R31, R26, and R27. Increased current through R30 and R31 places a higher voltage at the top of the resistors. An increasing voltage at this point brings the B+ voltage back to its proper value.

CHAPTER 8

CLOSED CIRCUIT TV APPLICATIONS

SYNCHRONIZING CIRCUITS

The discussion on closed circuit TV in chapter 7 is focused primarily on delivering the video signal to the picture tube. Equally important, from the point of view of overall receiver operation, is the system by which the various circuits are synchronized with those at the transmitter and made to function together to produce the desired picture. As had been stated before, the blanking pulses and the horizontal and vertical synchronizing (sync) pulses are amplified in the various stages along with the video information.

The detected composite video signal (contains synchronization pulses, blanking pulses, and video) is applied to the control grid or cathode (depending on phase) of the picture tube. The video information intensity modulates the scanning electron beam producing varying degrees of black through white information on the screen. The blanking pulses cut the picture tube off to prevent a visual indication of retrace. The sync pulses are present but have no effect since they are present during the time the picture tube is cut off and only drive the tube beyond cutoff.

After detection the composite video signal is also fed to a sync separation or clipper stage. The vertical and horizontal sync signals are removed from the composite video signal and filtered. Following this, the pulses are amplified and reshaped according to the needs of the synchronization and sweep systems. A block diagram of the synchronization circuits is shown in figure 8-1 with the associated pulse waveforms:

The horizontal sync signal fires the horizontal oscillator at exactly the right instant to maintain the proper synchronization between the horizontal sweep in the receiver picture tube and the horizontal sweep in the transmitter camera tube. The output of the horizontal oscillator is formed into a sawtooth waveform; it is then amplified and applied to the horizontal deflection coils.

The vertical sync signal fires the vertical oscillator at the right instant to maintain the proper synchronization between the vertical sweep in the receiver picture tube and the vertical sweep in the transmitter camera tube. As in the case of the horizontal oscillator output, the vertical oscillator output is formed into a sawtooth wave (modified into a trapezoidal form); it is then amplified and applied to the vertical deflection coil.

SYNC SEPARATORS

Sync separation, or sync clipping, may be accomplished by the use of circuits employing diodes, triodes, or pentodes. A simplified circuit of a diode sync separator is shown in figure 8-2. During the time the sync voltage is applied to the input, the diode plate is positive with respect to the cathode, and capacitor C is charged through the low resistance of the conducting diode. Between pulses, capacitor C discharges through R and thus maintains a negative bias between plate and ground; this cuts off all signals up to the blanking level. The bias is maintained at approximately the blanking level, and only the sync signal causes pulses of current to flow through RL, across which the output is taken.

The output pulses consist of the horizontal sync pulses, the equalizing pulses, and the serrated vertical sync pulses. These pulses are fed to filter circuits that separate the vertical sync pulses from the horizontal sync pulses.

The problems involved in removing (sync clipping) the sync signals from the composite signal, and in amplifying, separating, and utilizing those signals to control the horizontal and

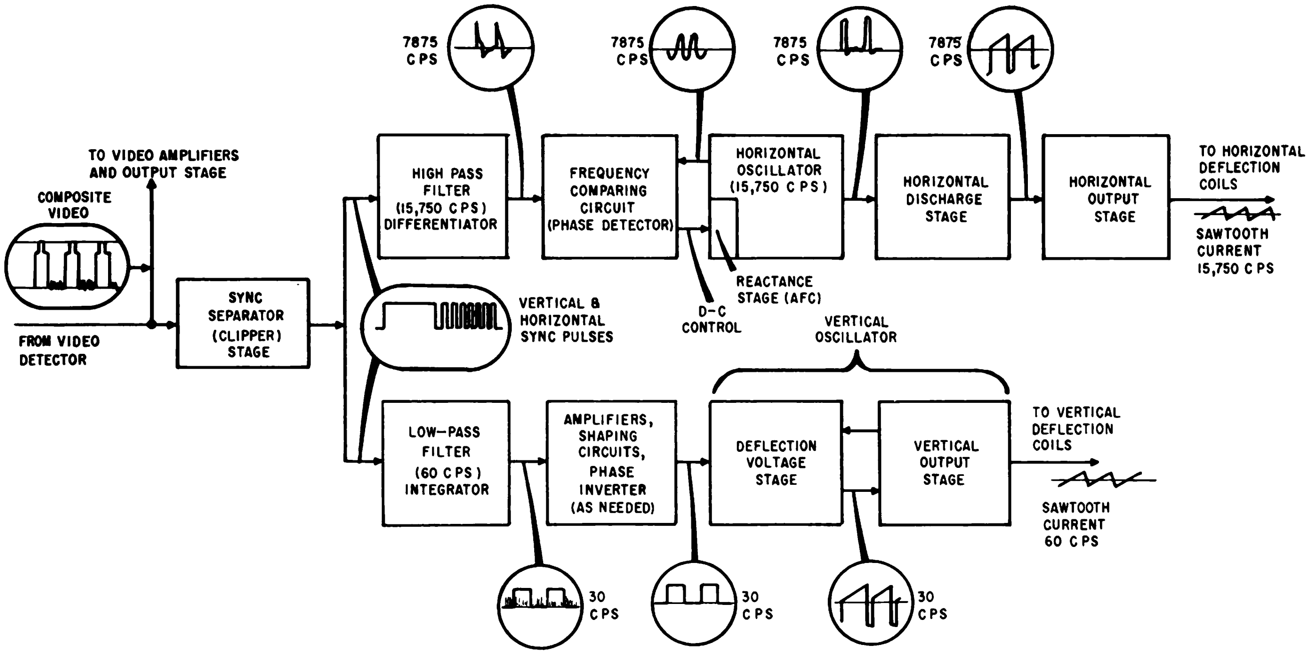

7875 CPS
7875 CPS
7875 CPS
7875 CPS
TO VIDEO AMPLIFIERS AND OUTPUT STAGE
COMPOSITE VIDEO
FROM VIDEO DETECTOR
SYNC SEPARATOR (CLIPPER) STAGE
HIGH PASS FILTER (15,750 CPS) DIFFERENTIATOR
FREQUENCY COMPARING CIRCUIT (PHASE DETECTOR)
HORIZONTAL OSCILLATOR (15,750 CPS)
HORIZONTAL DISCHARGE STAGE
HORIZONTAL OUTPUT STAGE
TO HORIZONTAL DEFLECTION COILS
SAWTOOTH CURRENT 15,750 CPS
VERTICAL & HORIZONTAL SYNC PULSES
D-C CONTROL
REACTANCE STAGE (AFC)
VERTICAL OSCILLATOR
LOW-PASS FILTER (60 CPS) INTEGRATOR
AMPLIFIERS, SHAPING CIRCUITS, PHASE INVERTER (AS NEEDED)
DEFLECTION VOLTAGE STAGE
VERTICAL OUTPUT STAGE
TO VERTICAL DEFLECTION COILS
SAWTOOTH CURRENT 60 CPS
30 CPS
30 CPS
30 CPS

Figure 8-1.—Block diagram of synchronizing circuits.

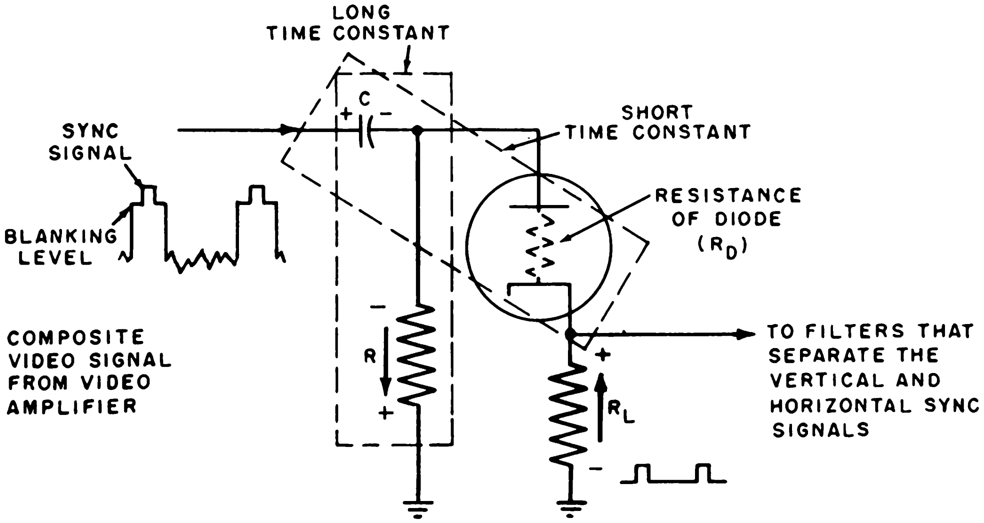

LONG TIME CONSTANT
SYNC SIGNAL
C
+
-
SHORT TIME CONSTANT
RESISTANCE OF DIODE (R_D)
BLANKING LEVEL
COMPOSITE VIDEO SIGNAL FROM VIDEO AMPLIFIER
-
R
+
+
R_L
-
TO FILTERS THAT SEPARATE THE VERTICAL AND HORIZONTAL SYNC SIGNALS

Figure 8-2.—Diode sync separator.

ertical oscillators are treated only in a general ay in this section. There are many methods of olving these problems, and therefore a detailed reatment of each method is not possible in this raining course.

eparation of Vertical and Horizontal Sync ulses

Because the repetition rate of the vertical ync pulses is 60 pulses per second and that f the horizontal sync pulses is 15,750 pulses er second, they can be separated by filters.

One filter, the high-pass filter, is used to ass and shape the trigger voltages for the orizontal oscillator (a multivibrator or blocking scillator) as shown in figure 8-3. The circuit n this figure has a short time constant with espect to the period (width) of the horizontal ulse. The output signal is developed across R.

The leading edge of the square-wave input ulses causes a rapid charge of C through R. he trailing edge causes an equally rapid disharge of C through R. The flow of charge and ischarge currents through R causes the sharp pikes of output voltage, as shown in figure 8-3. nly one spike in each pair (for example, the ositive spike) is needed to trigger the horiontal oscillator. The other spike of the pair ccurs at a time when the oscillator is inensitive to triggering pulses.

The low-pass filter used to pass and shape he trigger voltages for the vertical oscillator a multivibrator or blocking oscillator) is shown n figure 8-4. The RC time constant is long with respect to the width of each serration in the vertical pulse. Because of the long time constant in the integrator circuit, C does not have time to discharge during the interval between serrations. However, the RC time constant is short compared to the period of the combined vertical serrated pulses. Thus, C charges up to the peak value during the time that the vertical serrated pulse is applied (190.44 μsec in the figure) and discharges to zero before the next horizontal pulse arrives.

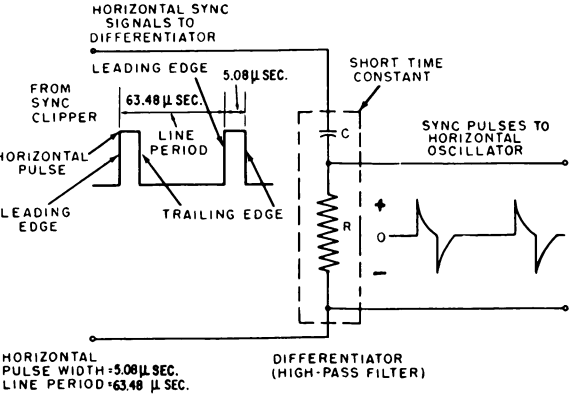


Figure 8-3.—High-pass filter for horizontal sync pulses.

This circuit is relatively insensitive to the longer, low-repetition-rate pulses that control the vertical oscillator. The reason is clear when you note that the time constant (with respect to the width of each horizontal pulse) of the differentiator circuit is short and the output is taken across the resistor.

Because of the long time constant (with respect to the width of each horizontal pulse) of the integrator circuit, the horizontal pulses have very little effect and the equalizing pulses have even less effect. The only pulse that produces a useful output is the serrated vertical pulse. Sixty of these pulses occur each second, 30 for each of the 2 fields. The vertical pulses are serrated to provide the triggering action for the horizontal oscillator during the vertical retrace period.

The sync separation circuit (and its associated waveforms) used in the monitor of the CCTV system, device X8F1, is shown in figure 8-5. The composite video signal with negative blanking appears at the video input jack. R118 is the sync clip level (gain) potentiometer from which the desired amplitude of signal is coupled through C109 to the control grid of V105.

C112 and R123 form a grid leak bias network for V106A. With grid leak bias and low plate voltage, tube current flows only during the uppermost 25 percent of the applied blanking and sync pulses. This action separates the sync pulses from the composite video signal. The output signals from V106A are negative sync pulses which are coupled to C113 to the control grid of V106B.

The control grid network of C113 and R128 establishes the bias for V106B. The sync pulses are amplified, and the positive pulses from the plate of V106B are routed to the vertical and horizontal sweep circuits.

Combined vertical and horizontal sync pulses are coupled through C114 to the integrator network consisting of R129 and C115. The network

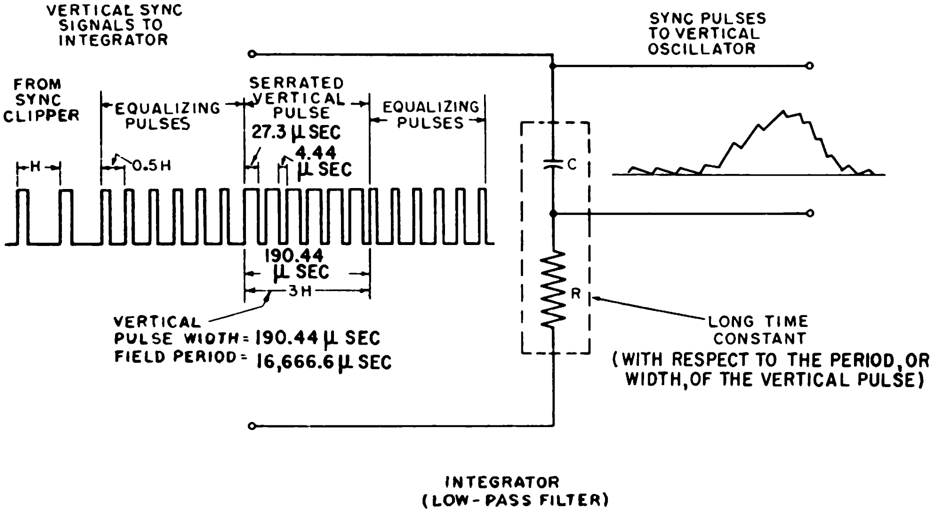

VERTICAL SYNC SIGNALS TO INTEGRATOR
SYNC PULSES TO VERTICAL OSCILLATOR
FROM SYNC CLIPPER
EQUALIZING PULSES
SERRATED VERTICAL PULSE
27.3 µ SEC
EQUALIZING PULSES
H
0.5 H
4.44 µ SEC
C
190.44 µ SEC
3H
R
VERTICAL PULSE WIDTH = 190.44 µ SEC
FIELD PERIOD = 16,666.6 µ SEC
LONG TIME CONSTANT (WITH RESPECT TO THE PERIOD, OR WIDTH, OF THE VERTICAL PULSE)
INTEGRATOR (LOW-PASS FILTER)

Figure 8-4.—Low-pass filter for vertical sync pulses.

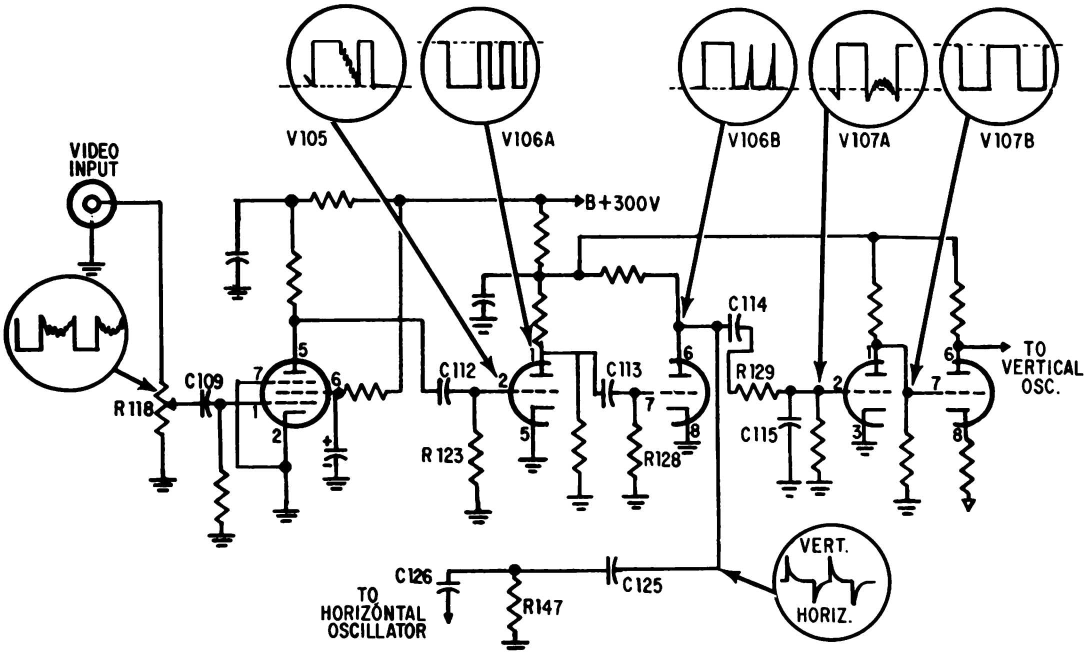


Figure 8-5.—Sync separation circuit.

offers a long time constant to the 5-microsecond horizontal pulses; thus, C115 will not accept a charge. However, the 190-microsecond vertical pulses will charge C115 due to their longer duration. Therefore, only the vertical pulses appear on the control grid of V107A. V107B is a direct-coupled amplifier which inverts and amplifies the vertical sync pulses. Its output is fed to the vertical sweep oscillator circuit.

Both vertical and horizontal pulses present at the plate of V106B are routed to the differentiator network consisting of C125 and R147. This network permits the horizontal pulses to pass and are coupled by C126 to the frequency comparing network.

SWEEP CIRCUITS

After being separated and shaped, the horizontal and vertical sync pulses are applied to the horizontal and vertical sweep oscillators, respectively, so that they may be triggered at the correct instant to synchronize the receiver with the transmitter. Both the vertical and horizontal sweep oscillators, when fed into the correct circuits, produce current sawtooth waveforms.

The sawtooth waveforms produced by the horizontal sweep oscillator are amplified and applied to the picture tube in a manner that will cause the electron beam to be deflected (swept) horizontally across the face of the tube. Likewise, the waveforms produced by the vertical sweep oscillator cause the electron beam to be deflected (relatively slowly) from the top to the bottom of the picture tube.

Multivibrators and blocking oscillators are two types of resistance-capacitance oscillators that are commonly used in the sweep circuits (vertical and horizontal) of television receivers. At this point it may be helpful to review the section describing these oscillators in Basic Electronics, NavPers 10087-A.

BLOCKING OSCILLATOR

A simplified version of a blocking oscillator is shown in figure 8-6 (A). When plate and filament voltages are applied to the tube, plate current begins to flow. A voltage is induced in the grid circuit (via transformer T) that makes the grid positive with respect to ground, and the plate current is thereby increased rapidly to saturation. Capacitor C2 charges rapidly during the time that grid current flows. At saturation the plate current and field about T stop increasing. The voltage induced in the secondary of T drops to zero, and therefore the induced positive grid voltage drops to zero. Capacitor C2 begins to discharge through R2 and the plate current falls; the field of T collapses. The voltage induced in the secondary of T is now of a polarity that aids the discharge of C2. The grid, therefore, becomes more negative with respect to ground, and plate current falls rapidly to zero. When the plate current is cut off, T's primary field reverses, causing the voltage at the plate of V1 to be higher than B+.

Capacitor C2 continues to discharge relatively slowly through R2. This action maintains a negative charge on the grid for an appreciable length of time. The time (equal to the period between the pulses produced by the oscillator) necessary for the negative charge to be reduced sufficiently to cause the tube to conduct again depends on the value of adjustable resistor R2. When the tube begins to conduct again, the cycle is repeated.

A sawtooth output could be tapped off across R3, but the waveform would be lacking in linearity and stability because of the loading effect on the oscillator. The sawtooth wave is developed because C3 charges relatively slowly through R3 during the relatively long time that V1 is cut off and discharges quickly through the tube during

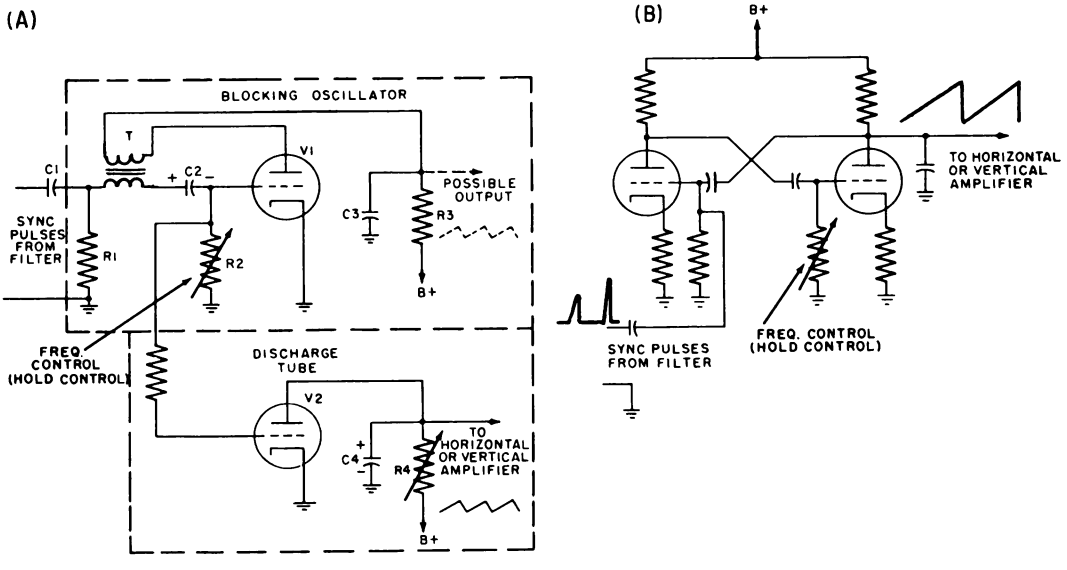


Figure 8-6.—Television sweep oscillators.

the relatively short time that the tube is conducting.

The sawtooth output is commonly obtained across the load resistor of a discharge tube. This arrangement is shown in figure 8-6 (A). The sharp positive pulse developed across R2 is coupled to the grid of V2. During the period when the positive pulse is not applied to the grid of V2, C4 charges relatively slowly at a uniform rate through R4; when the positive pulse is applied, C4 discharges rapidly through V2. The sawtooth voltage is therefore developed across R4.

MULTIVIBRATOR

A synchronized multivibrator circuit, which produces a sawtooth output, is shown in figure 8-6 (B). The sync pulses can control the firing of the multivibrator if the frequency of the multivibrator is slightly less than the frequency of the sync pulses.

VERTICAL SWEEP

The vertical sweep circuit (fig. 8-7) in the monitor unit produces a current which moves the electron beam of the picture tube from the top to bottom. The positive sync pulses from the sync separator circuit are coupled through C116 to the control grid of V108. V108 is a free running oscillator (trapezoidal generator). The sync pulse is timed to arrive just at the time V108 is ready to start its conduction cycle. The resulting change in the plate circuit of V108 is coupled to V109 through C121. This change is further amplified in V109.

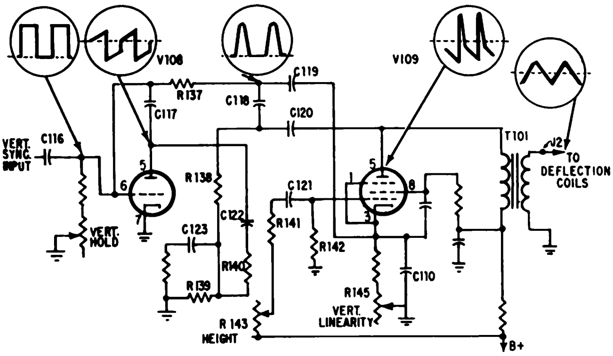


Figure 8-7.—Vertical sweep circuit, device X8F1.

C121 and R142 act as grid leak bia V109. C122, R139, and R140 form a shaping network. Capacitors C177, C118, C120 and resistor R137 form the oscillator back circuit back to the plate of V108. and C110 form a decoupler to ground for quencies above 60 cycles. R138, R139, and form a wave shaping circuit for the feed signal. Resistors R141 and R143 make u plate load for V108.

The height control (R143) varies the time for the charging cycle of C122. vertical linearity control (R145) varies bias of V109, thereby controlling the ga V109. Both of these controls (R143 and R145) vary the amplitude of the vertical sweep si Transformer T101 is used to couple the v cal sweep to the deflection coils on the pic tube through J2.

HORIZONTAL SWEEP

The sawtooth waves required for horiz deflection are developed in the horizontal s circuit (fig. 8-8). The horizontal oscill V111A is a (free-running) modified Armst type oscillator. The grid tank consists of L1 (upper half), C133, C134, C135, C136 (capac current coupler) and V103A, a capacitive r tance tube. C133, C134, and C135 are conne in parallel to provide stability in the eve tolerance fluctuations of any one capac The tickler coil is in the cathode circu V111A and is shown as the lower half of L1 C137 places the bottom of the oscillator circuit at a-c ground. C138 couples the circuit frequency to the grid pin of V111A signal is developed across R158 the resistor. The plate circuit of V111A cons of a ringing coil (70 kc to 90 kc) L102 th dampened by R160. R159 limits current to vide the proper plate potential for the oscilla

The frequency of the oscillator is de mined by the size of R158 and the grid circuit. With the oscillating sine wave from oscillator driving the discharge tube (V11 the sawtooth developed at the plate of V111 less than the necessary 53.34 microsec (sweep time) and the decay time much lo than 10.16 microseconds (blanking time). I is placed in the plate circuit of V111A to c pensate for the incorrect waveform an cause V111B to generate a sawtooth of the sired rise and decay time (note wavefor L102). L102 is a ringing coil placed in

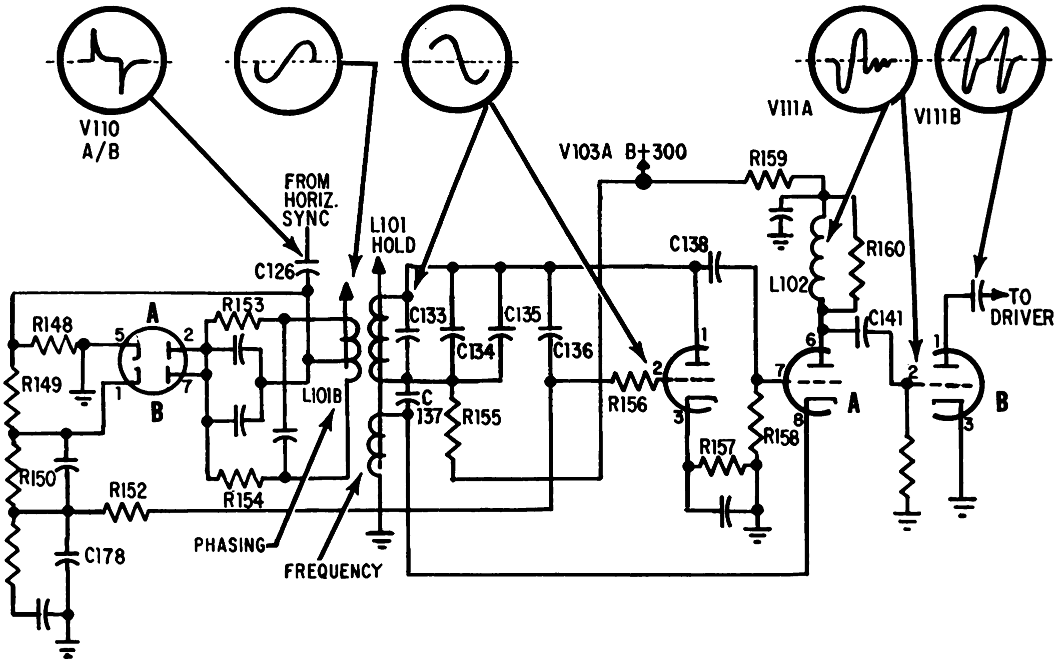


Figure 8-8.—Horizontal sweep circuit, device X8F1.

circuit to generate the large signal pulsing at 15,750 cps. The coil has an internal resonant frequency from 70 to 150 kc. R160 is placed in parallel with L102 as an oscillation damping resistor (swamping). The output of V111B is sent to the horizontal deflection and high voltage circuits.

AUTOMATIC FREQUENCY CONTROL (AFC)

In the sweep circuits discussed thus far, the horizontal and vertical sync pulses are fed from the filter directly to the horizontal and vertical sweep oscillators. This simple, direct system would be satisfactory if it were not for the presence of noise pulses that may cause the oscillators to fire at the wrong time. When the vertical oscillator fires at the wrong time, the picture is not properly synchronized vertically; that is, the picture bounces, or moves in jumps upward or downward across the screen. When the horizontal oscillator fires at the wrong time, the picture is not properly synchronized horizontally; that is, the picture tears or becomes streaked, giving the appearance that the picture is jumbled.

Although noise pulses may affect the operation of both the vertical and the horizontal oscillators, a far worse effect is felt by the horizontal oscillator. The long time constant of the vertical filter makes it insensitive to the short bursts of noise energy, and the effect on the vertical oscillator is not generally objectionable. In closed circuit TV, noise from electrical machinery can be just as destructive as atmospheric noise in a conventional home TV system.

The short time constant of the filter that feeds the sync pulses to the horizontal oscillator permits the passage of short bursts of noise energy. Consequently, it is necessary to employ a control circuit that effectively isolates the horizontal oscillator from the effects of noise pulses, and at the same time permits the sync pulses to assume control.

Two systems that isolate the horizontal sweep oscillator from the effects of noise bursts are shown in the block diagrams of figure 8-9. In the system shown in part (A), two signals are applied to the frequency discriminator. They are horizontal sync signals and horizontal sweep oscillator signals. The frequency discriminator compares the frequency (or phase) of these signals and produces an output d-c voltage that depends on the difference between the frequencies (or phase) of the two signals. The output voltage, normally varying at a relatively slow rate, is fed via a low-pass filter to the grid of the reactance tube. This tube functions in such

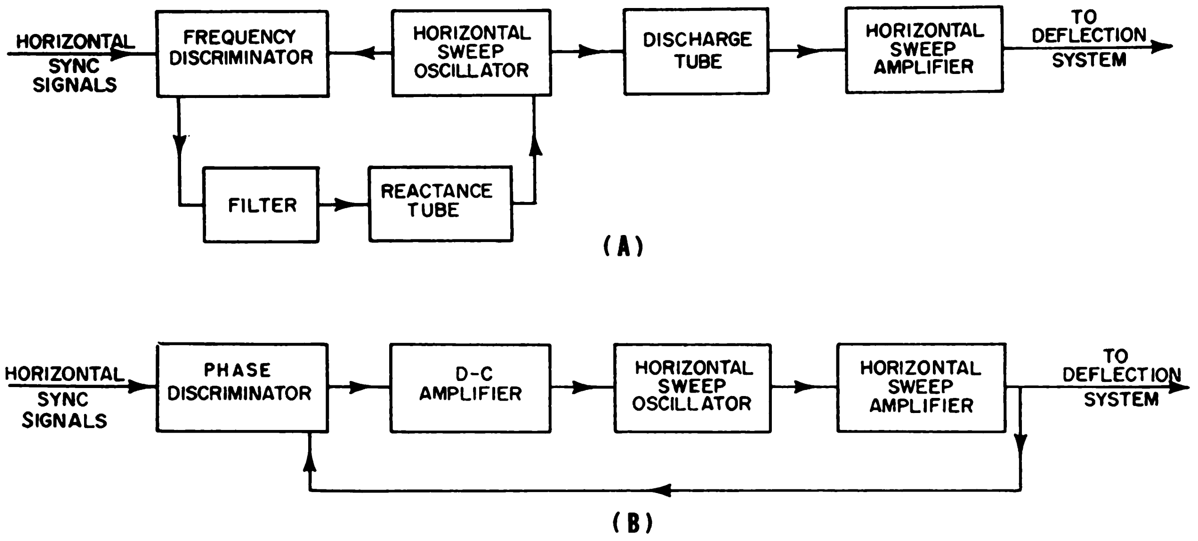


Figure 8-9.—Systems of horizontal sync control.

a manner that its output changes the frequency of the horizontal sweep oscillator to maintain its frequency exactly the same as that of the incoming horizontal sync pulses. Reactance tubes and frequency discriminators are discussed in Basic Electronics, NavPers 10087-A.

The second method of isolating the horizontal sweep oscillator from noise bursts is shown in figure 8-9 (B). As in the previous system, a frequency (or phase) discriminator is used. It compares the sync-signal input from the filter or sync amplifier with the input feedback from the horizontal sweep amplifier and produces a d-c output that is proportional to that difference. The manner in which this d-c output is amplified and used causes the frequency of the horizontal sweep oscillator to lock in step with the incoming sync signals.

The method of synchronizing the oscillator in the monitor (fig. 8-8) uses a control tube V103A. The discriminator circuit (V110) acts as an automatic frequency control by applying a varying amount of d-c voltage on the control grid of V103A.

The static condition of V103A has B+ applied to the plate through L101A and R155. Cathode bias is developed by R157. C178 is a decoupler which places a-c ground at R152. Voltage developed across R152 leads the voltage across C136 by 90°. The plate current through V103A leads the plate voltage on V103A by 90°, making the plate current appear capacitive. The conduction of V103A is present in the oscillator tank circuit and varies the oscillator's frequency. Hence, V103A operates as a variable capacitor (reactance modulator) automatically adjusting the oscillator's frequency in accordance with the discriminator (V110).

L101A induces a voltage in L101B which is 180° out of phase with the oscillator voltage. This voltage is then applied to the plates of V110. Sync pulses coupled from the sync separator by C126 are also placed on the plates of V110. The phase of the sync pulse is the same on both plates.

The purpose of the discriminator is to compare the two signals and to produce a d-c potential which is routed through R150, R152, and R156 to the grid of the control tube (V103A). Pins 5 and 2 of V110A represent ground potential when the tube is conducting. The amount V110B conducts determines the potential at pin 1 of V110 with respect to ground.

The incoming sync pulse charges and discharges C126 through three separate paths. These paths are as follows:

1. R148.
2. V110A, R153, and L101B.
3. R148, R149, V110B, R154, and L101B.

If the sync pulse and the horizontal oscillator sine wave are in phase, V110B conducts and a very small negative signal is developed across R149. This places a small negative voltage on the control grid of V103A, causing no change in the oscillator frequency.

If the horizontal oscillator frequency drifts, conduction of V110B increases, causing the cathode of V110B to go positive. A portion of this potential is impressed on the grid of V103A through R150, R152, and R156. The d-c potential on the grid of V103A brings the horizontal oscillator frequency back into phase with the sync.

If the horizontal synchronization is lost temporarily, the horizontal frequency slug (hold control L101A) can be adjusted to lock the picture in sync. The automatic frequency control circuit generally holds the picture in sync through one-half rotation of the hold control. The range through which the oscillator can be varied manually by the hold control and still hold the picture in sync is called the hold-in-range or lock-in-range. The range of frequencies through which the AFC circuit will react and can lock-in the oscillator after sync has been lost is called the pull-in-range. The pull-in-range is always less than the hold-in-range.

The horizontal hold control should be set at the middle of its hold-in-range so that the oscillator can be pulled into sync easily when changing channels.

Blanking of the picture screen has the timing of the sync and blanking pulses in the transmitted signal, but the flyback is determined by deflection circuits in the receiver/monitor. The position where the black blanking bars appear on the picture screen depends upon the phase of the scanning in the receiver/monitor deflection circuit with respect to the blanking pulses in the received video signal. If the receiver/monitor's horizontal system shifts out of phase, the black bar, which is normally on the left side of the screen, will shift into the center portion of the picture screen. The picture is locked in horizontally but split by the black bar. Adjusting the "phasing slug" L101B should place the receiver/monitor into phase with the transmitter/control unit.

HORIZONTAL DEFLECTION--HIGH VOLTAGE

All television receivers must have some type of high voltage power supply. Nearly all modern receivers, commercial and industrial, use the "flyback" type power supply. The "flyback" method uses the collapsing field of the yoke, introducing a high voltage pulse into the high voltage transformer, which is rectified, filtered, and applied to the picture tube.

Possibly the most important component of the system is the output (flyback) transformer. Because of its peculiar construction and method of operation, the transformer causes repairmen the most trouble.

Associated with the high voltage power supply is the "boosted B+" power supply. This voltage is derived from the conduction of a diode, which conducts during a portion of the horizontal sweep. The voltage is filtered and applied to special circuits within the receiver/monitor.

The voltages in the deflection and high voltage section range up to 30,000 volts and present a constant hazard to maintenance personnel. Safety precautions referred to in this training course and manufacturer's maintenance manuals should be carefully observed.

FLYBACK METHOD

The three tubes used in the high voltage system are specially constructed to supply the required voltages and currents. The horizontal output (driver) tube V1 is a pentode designed for high currents and voltage. V3 is the high voltage diode which rectifies the voltage for the picture tube. The damper tube (V2) is a diode which aids V3 in developing the extremely high voltage and in supplying the boosted B+ voltage.

A sawtooth voltage (approximately 70 v) from the horizontal oscillator is coupled by C2 and R1 to the control grid of V1. V1 will normally use grid leak bias. Cathode bias is developed by C3 and R2. This is a protective bias to limit plate current in the event that the input sawtooth voltage is lost.

Plate current of V1 flows from ground through R2, V1, L1, L6, V2, L2, and L5 to the B+ supply and back to ground. V2 must be conducting when plate current is flowing in V1 to complete the circuit. Notice that boosted B+ is being used for plate voltage of V1. C6 blocks the d-c component of the deflection amplifier from the deflection coils but passes the 15,750 cps horizontal deflection frequency.

Horizontal Scanning and Damping

The static or neutral beam position is in the center of the "raster" (the illuminated face of the picture tube). When V1 (fig. 8-10) conducts, the linear rise in current deflects the electron beam to the right side of the raster. During this time, energy is being stored in the output circuit transformer T1. (T1 is made up of L1, L2, L3, and L4.) When V1 cuts off, the output circuit starts oscillating. The first half-cycle allows a fast flyback from right to left of the electron beam. After retrace has been completed, the next half-cycle is damped by V2,

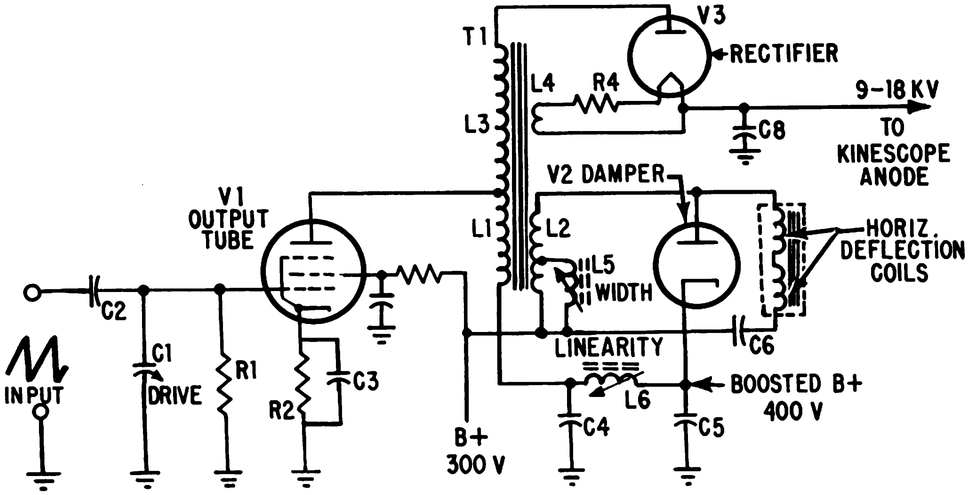


Figure 8-10.—High voltage and horizontal deflection.

causing the oscillation to decay to zero. The damped current in the deflection coils again starts the beam moving from left to right.

The oscillating action of the output circuit is approximately 70 kc--7 microseconds for one-half pulse, the time of the horizontal retrace.

Boosted B+ Voltage

Current flowing through V2 (fig. 8-10) charges the boost capacitor (C5) to the regular 300 v B+. The a-c deflection voltage across L2 makes the plate voltage of V2 100 volts more positive during horizontal trace time. This causes C5 to charge to 400 volts, the boosted B+ value. C4 and L6 form a filter network for the voltage.

High Voltage

The pulse produced in the horizontal output circuit (fig. 8-10) during the first half-cycle of oscillation for the flyback is used to develop the high voltage for the picture tube. This is accomplished by stepping up the a-c flyback voltage and supplying it to the plate of the high voltage rectifier (V3).

During retrace, a negative pulse of 1,000 to 2,000 volts is produced in the output circuit and is impressed into the flyback secondary. V2 does not conduct during this pulse. The positive pulse present at the plate of V1 and L1 is from 3,000 to 6,000 volts due to the step-up action from L2. L3 provides a step-up pulse that is from 9,000 to 20,000 volts for the plate of the high voltage rectifier (V3). When the pulse appears on the plate of V3, the tube conducts and charges C8. Since the frequency is 15,750 cps, the charging of C8 is sufficient to provide filtering.

The drive control (C1) varies the amount of sawtooth voltage present at the grid of V1 by acting like a voltage divider. The width control (L5) is in parallel with part of the secondary winding L2. Varying L5 varies the inductance which will widen the raster.

The amount of boosted B+ voltage varies as C5 charges and discharges. The operation of the output tube (V1) can be controlled by shifting the phase of the boosted B+ and the sawtooth grid voltage. Adjusting the linearity control (L6) will affect the stretching of the center portion of the screen.

The adjusting of the horizontal controls has three effects: drive affects the left side, linearity affects the center, and width affects the right side of the screen.

AUTOTRANSFORMER METHOD

In the autotransformer-coupled horizontal output circuit (fig. 8-11), the primary and secondary windings are not isolated. However, the circuit operation (scanning, damping, and boost voltage) is very similar to the mutual-coupled output circuit as shown in figure 8-10.

The sawtooth voltage from the discharge tube V111B (horiz osc) is coupled by C143 and R166 to the control grid of V112. Grid bias is developed by C143 and R165. Cathode bias is

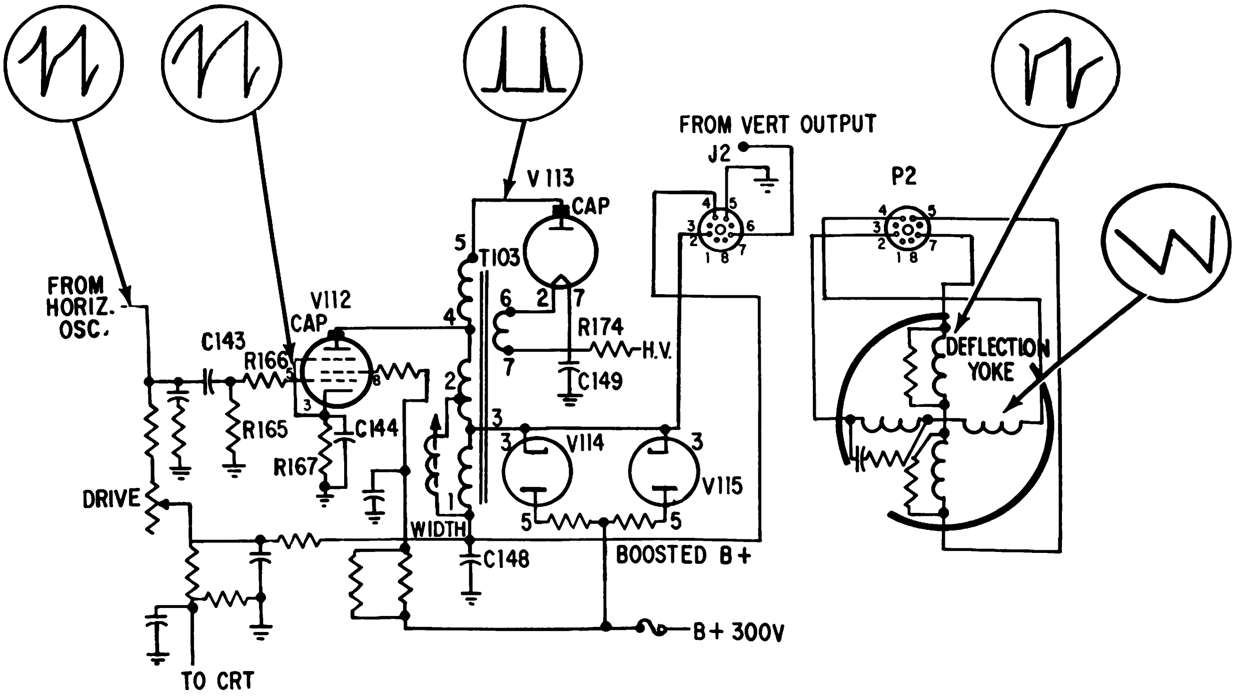


Figure 8-11.—High voltage and deflection circuit, device X8F1.

developed by R167 and C144. Plate current flows from ground through R167, V112, pins 4, 2, and 3 of T103, V114, V115, and to the B+ supply. V114 and V115 conduct when V112 conducts. When V112 cuts off, the output circuit starts to oscillate and is stopped. Boosted B+ is developed across C148. During flyback, the large pulse present in T103 (points 3 and 4) is stepped up by autotransformer action between points 4 and 5, placing the high voltage on the cap of V113. V113 rectifies the pulse across C149 and R174 providing the high voltage for the picture tube.

Because the flyback time is less than 10 μsec and both the inductance and the current change are relatively large, the induced voltage is very high. In some large screen picture tubes the voltage may be as high as 30,000 volts. Obviously, this voltage is dangerous, and care must be taken to see that the set is deenergized and that the filter capacitor is discharged before servicing the receiver.

During the time of the horizontal sweep, the current through the output transformer builds up steadily; and simultaneously, the magnetic field builds up. During the flyback time, the current is reduced sharply, and the magnetic field collapses. A large voltage is thereby induced in the primary winding. This voltage is applied between the plate of the high voltage rectifier and ground, and pulses of current flow through the rectifier during the flyback time. Because of the large number (15,750) of pulses occurring each second, a small capacitance may be used in the filtering arrangement.

The horizontal output transformer commonly has a powdered-iron core to avoid the annoying vibrations that might be set up at the horizontal sweep frequency if a laminated core were used. The filament power supply is obtained from a secondary winding composed of one or two turns of wire.

In this type of circuit, failure of the low voltage supply automatically removes the high voltage. This is an advantageous arrangement because if the horizontal sweep were removed, without removing the high voltage at the same time, the screen might be damaged at the point where the electron beam strikes it.

REMOTE OUTPUT

The method of transmitting the amplitude-modulated television picture signal is similar to the familiar system of sound transmission in the standard AM radio broadcast system. In both systems the amplitude of an RF carrier is caused to vary.

In TV broadcasting the composite video signal modulates a high frequency carrier wave. The modulated picture carrier is the composite video signal containing all the information needed for picture reproduction. At the receiver the picture signal is detected to recover the composite video signal which is then used to reproduce the picture.

In CCTV the transmitter is a low powered system which radiates the signal over a selected coverage. Conventional TV receivers receive the transmitted signals of the CCTV system exactly the same as the commercial broadcasting stations. An unused channel is selected for the CCTV transmission so that no interference will occur from the reception of other stations. The frequencies for television broadcasting are assigned by the Federal Communications Commission and are grouped as follows:

1. Five low-band channels (2 through 6) in the VHF range occupy from 54 to 88 mc.
2. Seven high-band channels (7 through 13) in the VHF range occupy from 174 to 216 mc.
3. Seventy UHF channels (14 through 83) occupy from 470 to 890 mc. Each channel is allotted 6 mc for the transmission of the video and sound signals.

A wide video bandwidth of 4 mc (8 mc for upper and lower sidebands) is necessary in order to transmit pictures having good definition. With a band of 6 mc assigned, the video requirements present a problem. To reduce the bandwidth required for video, only a portion of one sideband (lower), along with the upper sideband is transmitted. This method of transmission is called "vestigial sideband." The video occupies 4.5 mc, leaving the remaining 1.5 mc for the sound portion and channel separation. In installations that require sound, a separate FM transmitter is employed. FM transmitters are discussed in Basic Electronics, NavPers 10087-A.

The CCTV transmitting system employs a relatively simple circuit (fig. 8-12). The raw video from the camera unit connects to the circuit at the control grid of V1A. V1A, V1B, and V2A are conventional video amplifiers utilizing shunt peaking. V2B is a pentode video amplifier. CR1 in the grid circuit of V2B acts as a d-c restorer which maintains the black level of the video at a constant voltage. The video signal on the control grid and the syn pulses coupled on the cathode are combined i V2B to produce the composite video signal. Th composite video signal is coupled from V2 through C8 to the control grid of V3A.

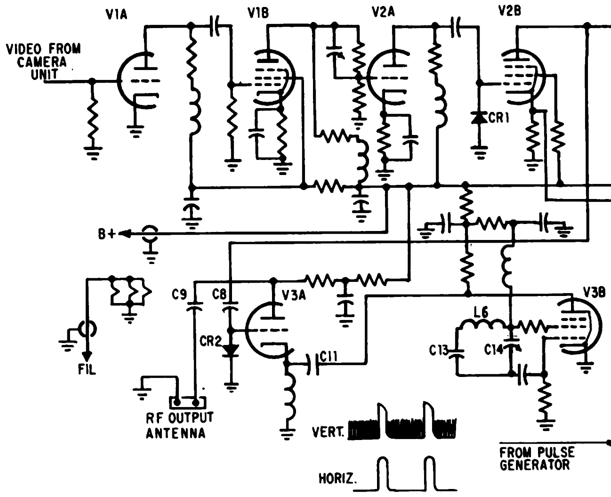


Figure 8-12.—CCTV transmitter.

V3B is an electron-coupled oscillator. Th oscillating tank consists of L6, C13, and C14 Adjusting C14 varies the frequency from 54 t 88 mc (channels 2 through 6). The output of th oscillator is coupled from the plate of V3 through C11 to the cathode of V3A.

V3A is the modulator output tube. The composite video is applied to the control grid a an established value by the d-c restorer (CR2) CR2 conducts on the positive peaks, thereb clamping the composite video at a negative value The RF oscillator sine wave is applied to th cathode of V3A. Amplitude-modulated output i coupled through C9 to the RF output terminals An antenna system can be connected for radiation of the signal, or the output connected t power amplifiers for long range transmission

REMOTE RECEPTION

In common with other electronic receivin equipments, the TV transmission line function to convey (with minimum distortion and minimum loss) the signal from the antenna to th receiver. To satisfy these requirements, th line should be balanced to ground (that is, eac of the conductors should have the same capacitance with respect to ground); and the primary of the input circuit should be center tapped. Undesired signals induced in the lin are thus balanced out and do not affect the operation of the receiver. To reduce losses, the transmission line should have low effective resistance, and the characteristic impedance should be the required value to match the antenna and the receiver input for maximum power transfer.

A number of transmission lines may be used with television receivers; for example, the twisted pair, the shielded pair, the coaxial line, or the twin line.

The type of antenna used will vary with the particular installation. The antennas shown in figure 8-13 are some of the simpler types. The primary purpose of all TV antennas is to intercept the maximum amount of desired signal energy and to make it available at the input of the transmission line.

Several factors, such as economy, flexibility, low loss, and impedance match, have led to widespread use of the 300-ohm twin line. The conductors, spaced at a distance of about 3/8 inch, are embedded in a plastic ribbon. Although this type of line has several good features, it should be pointed out that weathering will change its characteristic impedance; and, because of a lack of shielding, its use may not be advantageous in areas where there is a large amount of electrical disturbances. Most shipboard and aircraft installations utilize shielded transmission line, as they have for other VHF and UHF installations, and for the same purposes.

TELEVISION RF AMPLIFIERS, OSCILLATORS, AND MIXERS

Television tuners, like those of communications receivers, consist essentially of three parts: the RF amplifier, the oscillator, and the mixer. The function of the front end (composed of the RF amplifier, the oscillator, and the mixer) is to amplify the relatively weak input

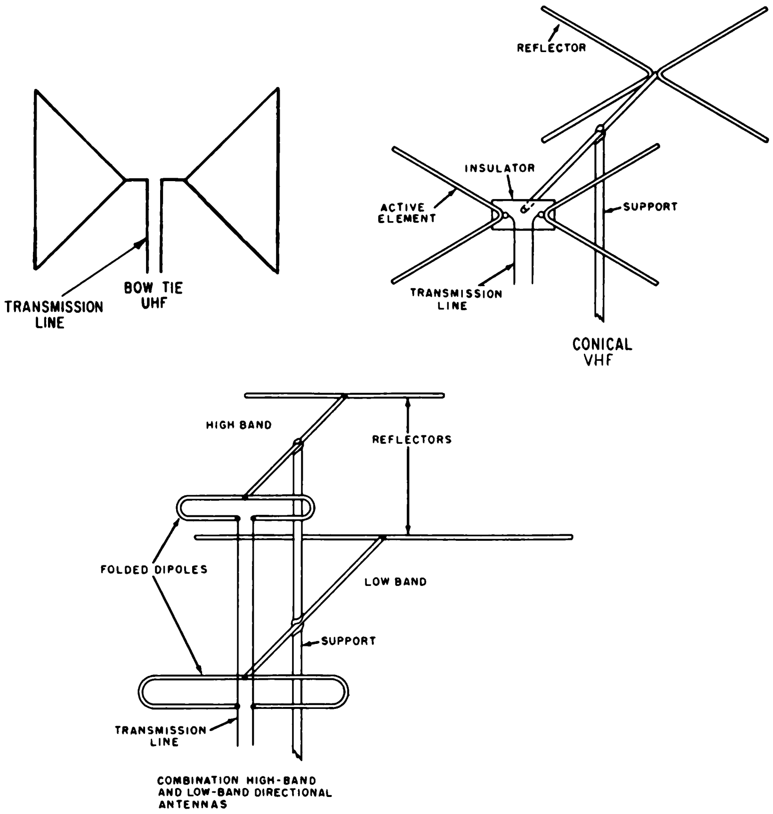


Figure 8-13.—Television antennas.

signal of the desired frequency, to produce a locally generated RF signal of the correct frequency, and to mix these two frequencies in such a way as to produce the chosen audio and video intermediate frequencies. Because of the wide band of frequencies (approximately 6 mc) that must be passed, overcoupling and loading are employed to increase the frequency response.

A block diagram of a typical front end is shown in figure 8-14. A number of different methods of tuning are employed by television receiver manufacturers, and consequently, many different types will be encountered by the Tradevman. Rotary switches that connect the correct capacitors and inductors into the circuit are often employed. In some systems the "tuned line" is used, and in others separate components are connected for each channel. Turret tuners are also widely used. In this system of tuning, elements pretuned to the desired frequency may be plugged into a clip in the turret. For compactness and precision, printed circuits are sometimes employed.

Although certain problems are involved in continuous tuning, various forms of continuous tuners are used in a number of sets. The Inductuner, produced by the Mallory Company, is a popular tuner in which the inductance is varied over the tuning range while the capacitance remains constant.

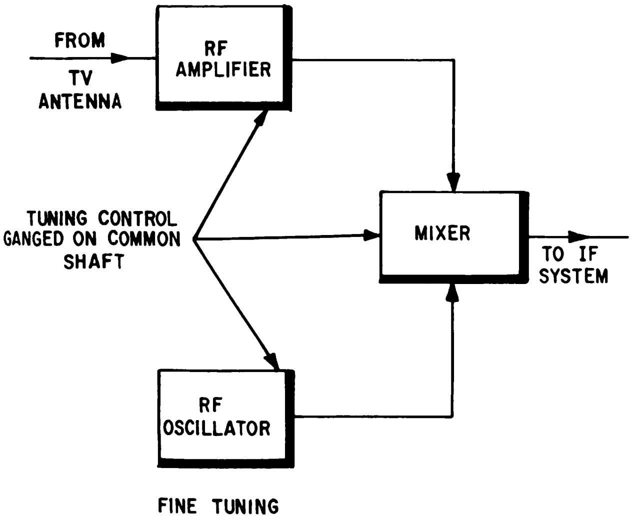


Figure 8-14.—Block diagram of a TV front end.

RF AMPLIFIERS

Because the television signal available at the input of the television receiver is weak, it is desirable to amplify the signal in a stage of RF amplification before it is applied to the mixer. Pentode tubes may be used to obtain high amplification, but the band of frequencies passed is reduced unless the plate load resistor is reduced. If this is done, the gain is reduced and there is less advantage in using a pentode. Therefore, a triode having a high transconductance is sometimes used. The triode is also inherently less noisy (because it has fewer grids) than the pentode, and this is a definite advantage when weak signals are being received. Obviously, if noise is amplified as much as the signal, "snow" and other undesirable effects appear on the screen.

A popular RF amplifier, the cascode amplifier, combines the good features of both the triode and the pentode. A simplified circuit of one type of cascode amplifier is shown in figure 8-15.

Signals from the antenna are developed across the tuned circuit C1 L1 and inductively coupled to L2. The frequency response is improved by effectively shunting L2 with R1. Neutralization is not necessary for operation on the low band because of the compact arrangement of the circuit and the tube connections. Likewise, neutralization is unnecessary for operation on the high band because L3 and C2 (the distributed capacitance to ground) form a series-resonant circuit (resonant at the center of the high band) from the plate of V1 to ground. The signal voltage across L3 varies the potential of the cathode of V2 with respect to ground; and, because the grid is grounded, the signal is applied effectively between the cathode and the grid of V2. This arrangement, in effect, nullifies the shunting distributed capacitance insofar as injecting undesired noise or degeneration into the grid circuit of V1 and V2 is concerned.

OSCILLATORS

Although many radio receivers employ a common tube for the oscillator and mixer, it is usually more satisfactory for frequencies used in commercial TV, to use a separate oscillator tube. Triodes are generally used in one of a number of possible circuit arrangements.

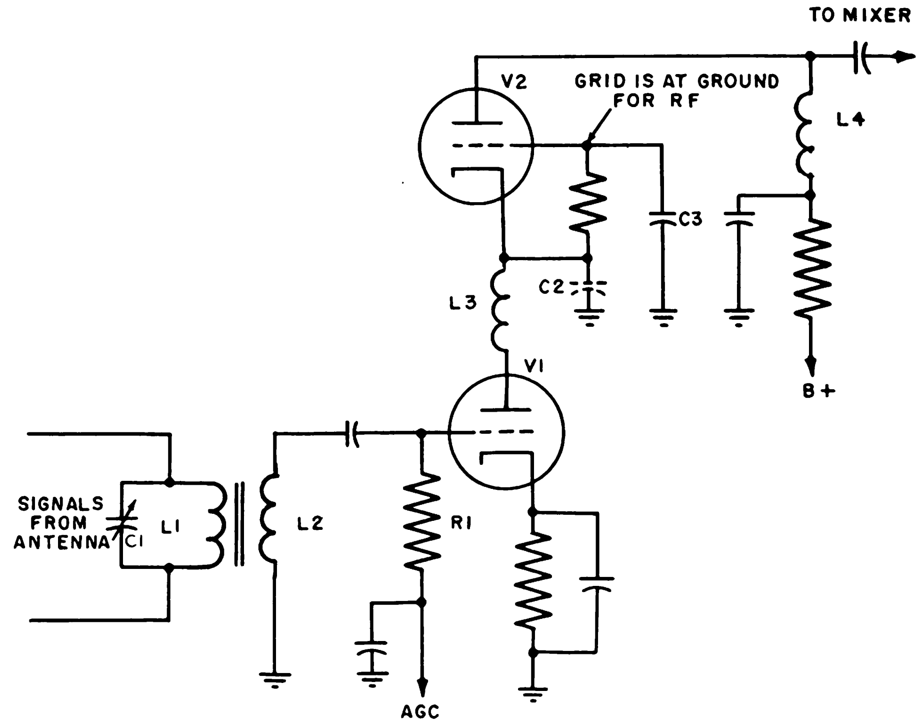


Figure 8-15.—Tuner RF amplifier.

The ultra-audion oscillator, similar in many respects to the Colpitts oscillator, is often employed. In other receivers, the Hartley circuit, the Colpitts circuit, or some form of push-pull arrangement is used. Oscillators are discussed in Basic Electronics, NavPers 10087-A.

The fine tuning control is included in the oscillator circuit.

MIXERS

The mixer tubes commonly used in TV receivers are triodes or pentodes. As in the case of RF amplifiers, triode mixers are less noisy than pentodes. However, they lack the gain of pentodes. Diodes introduce little or no noise, but they do not add gain. Energy is coupled from the oscillator into the mixer by capacitive or inductive means. Mixers are also discussed in Basic Electronics, NavPers 10087-A.

VIDEO IF AMPLIFIERS, DETECTORS, AND D-C RESTORERS

Video IF amplifiers perform essentially the same functions that are performed by the IF amplifiers in superheterodyne radio receivers. However, bandpass considerations, vestigial sideband transmission, the necessity for trapping unwanted sound and video beat frequencies, and other factors make the design of video IF amplifiers somewhat difficult. A detailed discussion of the various types of video IF amplifiers is beyond the scope of this training course. However, the overall problems and some of the methods used to solve them are given.

Perhaps the best approach is to list the various problems inherent in the video IF section of a television receiver and to indicate one or more methods of solving each of the problems.

FIRST: For RF spectrum economy, the lower video sideband is greatly suppressed, and the video information is contained largely in the unsuppressed upper sideband. The remaining portion of the lower sideband is the vestigial sideband. The general form of the television RF spectrum is shown in figure 8-16.

Because it is impracticable to remove all of the lower sideband, the response curve of the video IF stage must have a special form. In general, the response curve is similar to

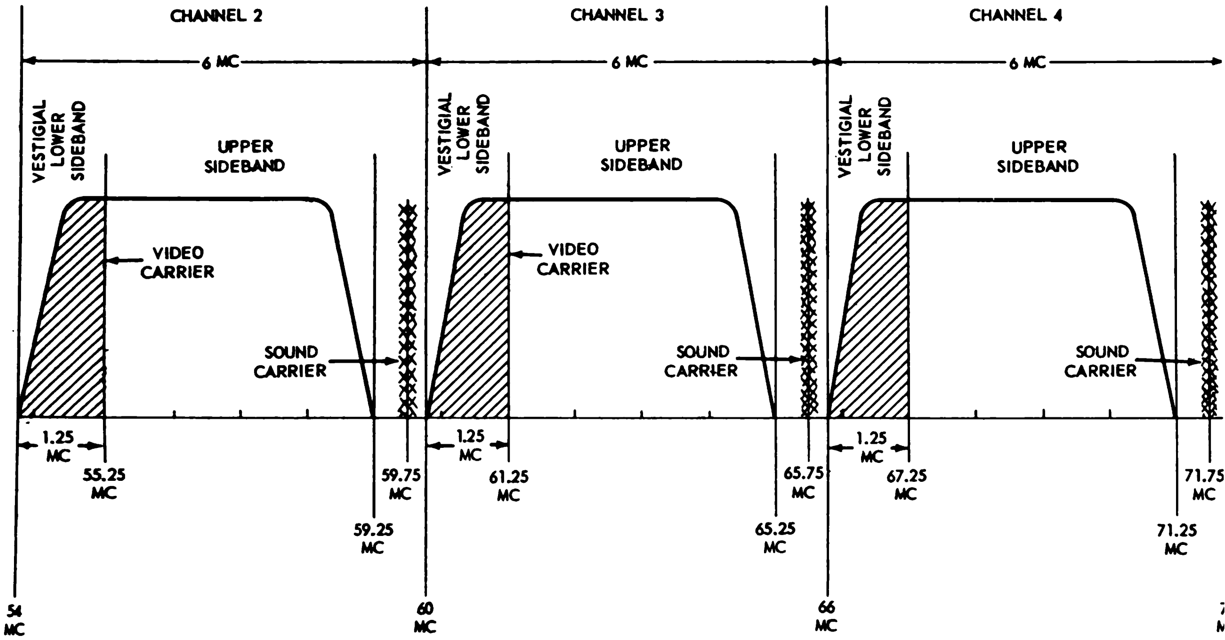


Figure 8-16.—RF spectrum for TV channels 2, 3, and 4.

hat shown in figure 8-17. It may be seen that he video IF has a higher frequency than the sound IF. This results from the fact that the ocal oscillator operates at a higher frequency han that of the incoming signal.

That portion of the sidebands extending 1.25 nc on both sides of the video carrier contains nore energy than the sidebands beyond 1.25 nc (fig. 8-16). This results from the fact that oth upper and lower sidebands exist in the 1.25 nc bandwidth in the immediate vicinity of the ideo carrier; whereas, beyond 1.25 mc, only he upper sideband is present. If the IF ampifiers were flat over the video band, the freuencies between 0 and 1.25 mc on each side of he video carrier would be overemphasized at he second detector. In other words, the ampitude of these signal frequencies would be reater than that of the remaining frequencies n the upper sideband of the video signal ecause of the increased energy associated with he frequencies between 0 and 1.25 mc on each ide of the video carrier.

In order to achieve uniformity in the magitude of the output video signal for all freuency components, the IF stages are adjusted o that the video IF carrier falls about halfway down on the upper slope of the response c The lows are therefore amplified less tha highs, and a more uniform response is achi For example, a receiver tuned to chan having a video carrier of 61.25 mc may a local oscillator frequency of 107 mc. T bandwidth will then extend from 107-61. 45.75 to 107-65.25 = 41.75, or a tot 45.75-41.75 = 4 mc. In the alinement of vid stages, this adjustment is very impo

SECOND: Because the response ch teristic of the RF and converter stage intentionally broadened to pass the desired of frequencies (6 mc), the sides of the resp curve taper off gradually. This means undesirable frequencies may be passed th to the video IF system, which may cause zontal bars to appear on the picture. example, it is assumed that a television rec employing a split-sound system is tune channel 3. (In a split-sound system the au taken off before the detector stage; whe in intercarrier-sound systems the aud taken off after the detector stage.) The quencies (39.75 mc, 41.25 mc, and 47.75 that may cause trouble on the television s are indicated in figure 8-17. The 39.75-mc

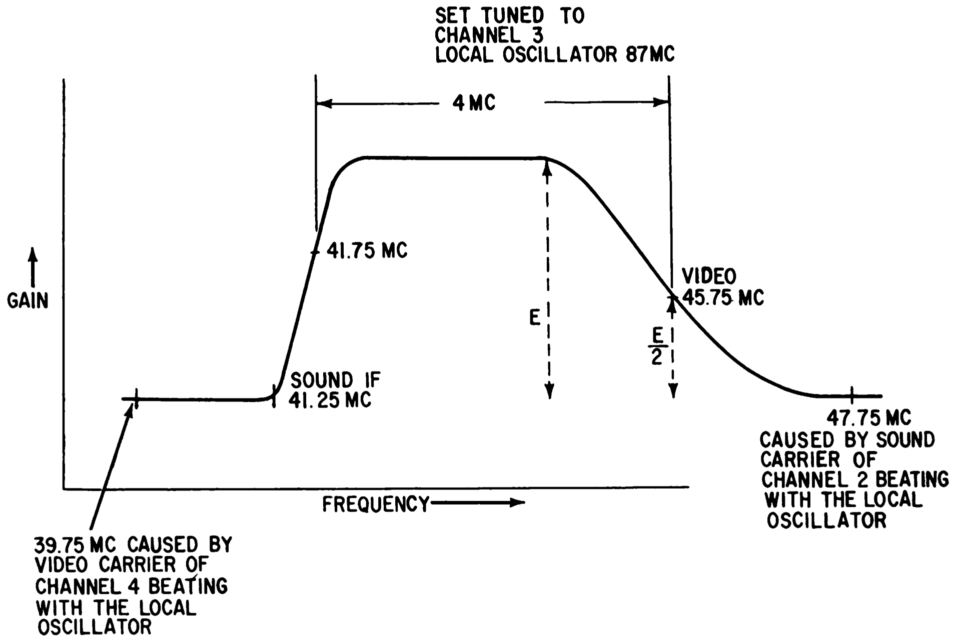


Figure 8-17.—Video IF response curve.

note, caused by the combining of the video carrier (67.25 mc) of channel 4 with the local oscillator frequency (107 mc), is close enough to the desired frequencies to be passed through to the video IF system. Likewise, the 47.75-mc beat note, caused by the combining of the sound carrier (59.75 mc) of channel 2 with the local oscillator frequency (107 mc), is close enough to be passed also. Of course, the sound IF (41.25 mc) of channel 3 is the signal most likely to get through and must be trapped out. In intercarrier systems this frequency, which beats with the video IF to produce the 4.5 mc sound IF, must not be removed until after the sound IF (4.5 mc) has been fed to the audio channels.

Some representative trap circuits are shown in figure 8-18. An absorption trap is shown in part (A). The trap is tuned to the undesired frequency, and the output voltage (at the undesired frequency) developed across L is greatly reduced. It is therefore effectively removed from the input to the next stage.

A degenerative trap is shown in figure 8-18 (B). At its resonant frequency (the undesired frequency) the trap offers a high impedance and this causes degeneration and reduced gain at that frequency.

A series-resonant trap is shown in figure 8-18 (C). The trap is tuned to the undesired frequency and thus shunts these frequencies around the input of the stage.

The parallel-resonant trap, shown in figure 8-18 (D), offers a high impedance to the undesired frequency. Thus, the offending voltage is dropped across the trap circuit and is not available at the input of the next stage.

Although trap circuits are commonly employed in the video IF stages, they are sometimes also included in the video amplifier o television receivers.

THIRD: In order to pass the necessary wide band of frequencies, most television receivers employ a stagger-tuned IF system. Each stage is tuned to a slightly different frequency to broaden the overall response curve. As an example, it may be assumed that a quality television receiver, employing split sound and stagger tuning, is tuned to channel 3. It may be assumed also that the local oscillator operates at 107 mc.

The video IF is

107 mc-61.25 mc = 45.75 mc

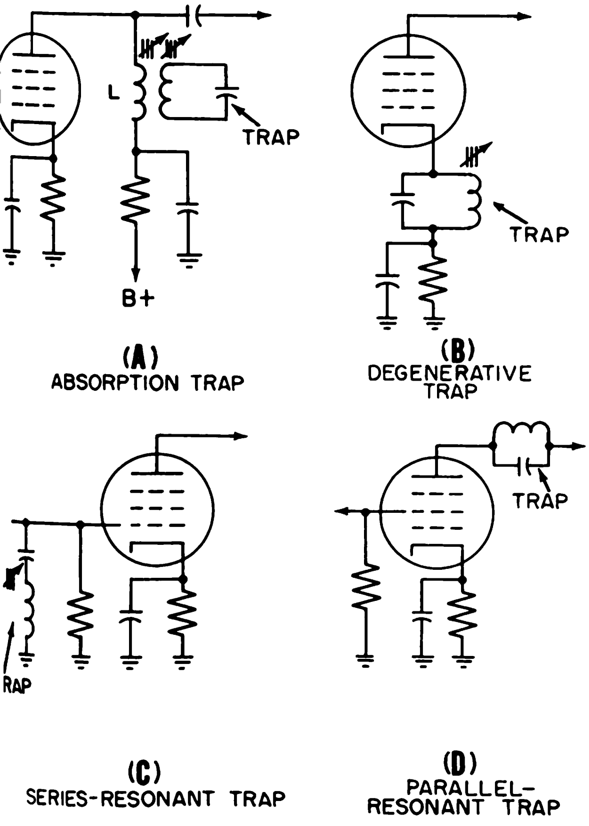
and the sound IF is

107 mc-65.75 mc = 41.25 mc

The various tuned circuits in the IF section together with the traps) are shown in figure -19 (A). The various frequencies in the vicinity f the video IF are so chosen that the overall esponse curve is similar to that shown in (B).

VIDEO DETECTORS

The video detector in a television receiver erforms essentially the same function as the econd detector in a superheterodyne amplitude-odulated radio receiver. It rectifies the signal ideo and sync pulses) fed to it by the video F system, removes the IF components, and eeds the remaining signal and sync information the video amplifier. Various circuit arrange-ients, employing either diode electron tubes or rystals, are used by the manufacturers of tele-ision receivers.



(A) ABSORPTION TRAP

(B) DEGENERATIVE TRAP

(C) SERIES-RESONANT TRAP

(D) PARALLEL-RESONANT TRAP

Figure 8-18.—Trap circuits.

One type of diode detector is shown in figure 8-20 (A). Two methods of connecting the detector are shown. The output of V1 has a negative picture phase, and V2 has a positive picture phase.

In figure 8-20 (A), the low amplitude positive-going picture signals correspond to the brighter portions of the picture and higher amplitudes correspond to progressively darker portions of the picture. This corresponds to the negative picture phase.

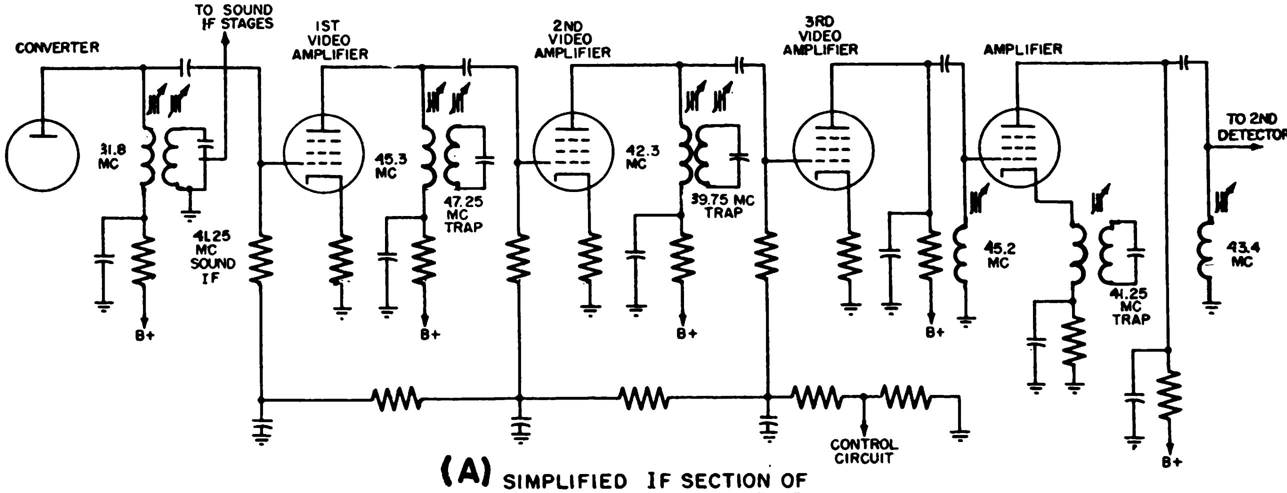
The low amplitude negative-going picture signals of V2 correspond to the brighter portions of the picture and higher amplitudes correspond to progressively darker portions of the picture. This corresponds to the positive picture phase.

The concept of negative picture phase may be made clearer from the following considerations. A video signal having a negative picture phase causes the cathode of the picture tube to be driven in a positive direction beyond cutoff during the blanking pulses. During the darker portions of the picture, the cathode is considerably in the positive direction, but not to cutoff. Consequently, a few electrons reach the picture tube screen, and the screen is relatively dark. During the brighter portions of the picture the cathode is driven only slightly in the positive direction, and many electrons reach the picture tube screen. The screen is therefore relatively bright.

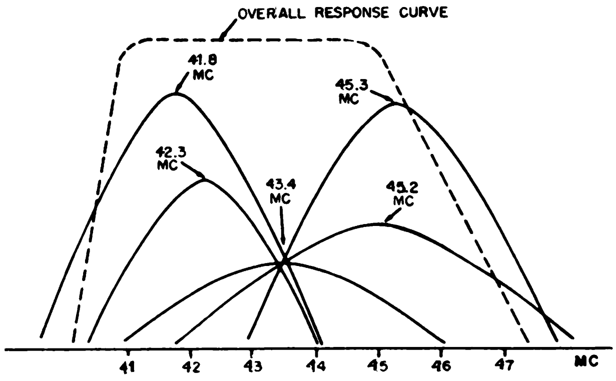
The concept of positive picture phase may be made clearer from the following considerations. A video signal having a positive picture phase causes the grid of the picture tube to be driven negative below cutoff during the blanking pulses. During the darker portions of the picture the grid is driven considerably negative, but not to cutoff. Consequently, fewer electrons reach the picture tube screen, and the screen is relatively dark. During the brighter portions of the picture, the grid is driven only slightly negative, and many electrons reach the picture tube screen. The screen is therefore relatively bright.

In the United States, negative transmission is used; that is, the television signal is transmitted with the negative picture phase. In certain other countries, positive picture transmission is used.

The output of the detector in the receiver may have a positive or a negative picture phase as indicated in figure 8-20 (A), irrespective of the type of transmission used. In either case, the video amplifiers must supply a signal having



(A) SIMPLIFIED IF SECTION OF TV RECEIVER EMPLOYING SPLIT SOUND



(B) APPROXIMATE IF RESPONSE CURVES

Figure 8-19.—IF section and response curve.

a positive picture phase to the grid of the picture tube. If the signal is applied to the cathode of the picture tube, it must have a negative phase.

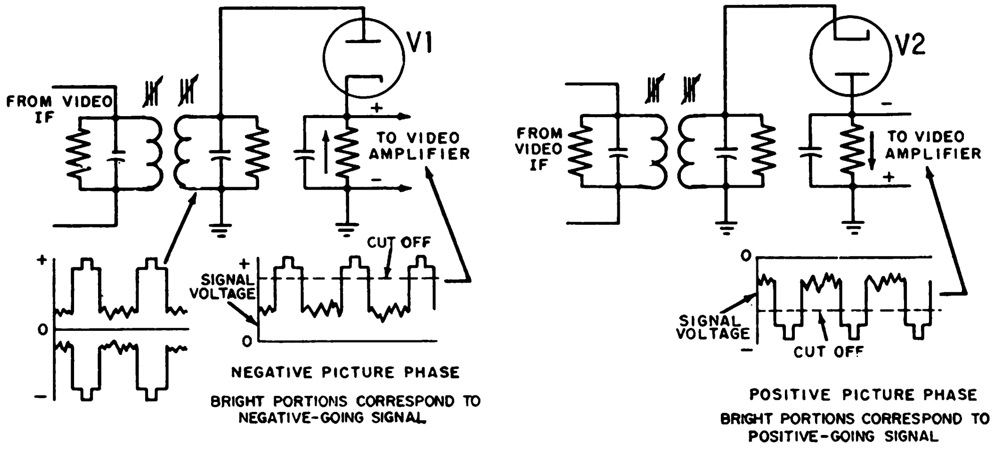
The strength of the signal at the output of the detector is not sufficient to drive the picture tube, and therefore one or more stages of video amplification are necessary.

The circuit arrangement of a video crystal detector is shown in figure 8-20 (B). The crystal performs essentially the same function as the diodes.

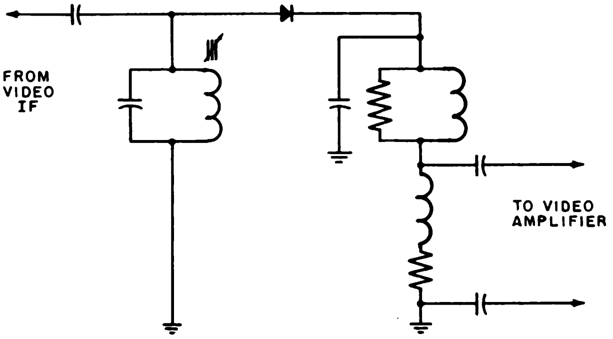
VIDEO AMPLIFIERS AND D-C RESTORERS

Video Amplifier Design Problems

After the video signal (containing the video information and the blanking and sync pulses) has been rectified in the second detector, it must be amplified in one or more video amplifiers before it is applied to the picture tube. Because a wide band of frequencies must be passed without discrimination by the video amplifiers, they must be carefully designed.



(A) VIDEO DIODE DETECTORS



(B) VIDEO CRYSTAL DETECTOR

Figure 8-20.—Video detectors.

pecial high and low frequency compensating ircuits must be used to extend the approximate ange of frequencies passed from 30 cycles to mc. In other words, frequency distortion must e eliminated as much as possible.

The low frequency video components include he low frequency a-c variations (represented n the picture screen as portions of the image hat do not contain fine detail), the blanking ulses, and the sync pulses (vertical and horiontal). The high frequency video components re the high frequency a-c variations that prouce the fine detail on the picture screen. In ddition to the low frequency and the high freuency components in the transmitted signal, here is a zero frequency, or d-c, component resent.

If all of the frequency components are not properly amplified in the video amplifier section, a distorted image is produced. The distortion may appear as a lack of fine detail, a lack of image sharpness in the larger objects, or a lack of contrast.

In addition to frequency distortion, phase distortion must also be eliminated as much as possible. In effect, phase distortion means that certain components (frequencies) that make up complex waveforms are not passed by the amplifier in the same length of time that other frequencies are passed. For example, in resistance-coupled amplifiers the coupling capacitor and the grid resistor, acting together, cause a phase shift that varies with the frequency.

Phase distortion may alter the background of the picture shown on the television screen; portions that should be white may be gray or even black. At the lower frequencies, excessive phase shift may cause larger objects to be blurred on the screen. At the higher frequencies, excessive phase shift causes the fine detail to be blurred.

Methods of Eliminating Frequency and Phase Distortion

Video frequency amplifiers are discussed in Basic Electronics, NavPers 10087-A. It is pointed out that the average resistance-coupled amplifier has a flat response of only a few thousand cycles and is therefore not suitable for amplifying video frequencies.

In order to amplify the higher frequencies as much as the middle range of frequencies, it is necessary to use some form of high frequency compensation. This type of compensation commonly takes the form of shunt compensation or series compensation or a combination of both.

In a resistance-coupled amplifier the output capacitance of the first amplifier stage, the distributed capacitance of the wiring, and the input capacitance of the second amplifier stage tend to shunt the high frequencies of the first stage to ground, thereby leaving less output voltage at these frequencies available to the second stage. The high frequencies are therefore not amplified as much as the middle range of frequencies.

This shunting effect may be compensated for (or the frequency range extended) by the use of a small inductor inserted in series with the plate load. The value of this inductor is so chosen that it will neutralize the distributed (output and input) capacitance of the circuit. That is, this inductor together with the distributed capacitance, forms a parallel-resonant circuit that is resonant at a frequency where the response curve begins to fall appreciably. The frequency range is thereby extended. This type of compensation is called shunt compensation, and the coils are called peaking coils.

Series compensation may also be used. In this case, a small inductor is added in series with the coupling capacitor and forms a series-resonant circuit (resonant at a frequency where the response curve begins to drop) with the distributed capacitances. At resonance, increased current flows through these capacitances, and larger voltages are available at the input of the amplifier tube. To prevent a sharp peak in the response curve, a resistor is shunted across the series inductor.

In order to amplify the lower frequencies as much as the middle or high range of frequencies, it is necessary to use some form of low frequency compensation. At low frequencies, the reactance of the coupling capacitor is large and much of the signal voltage is dropped there and is not available at the grid input. A large coupling capacitor could be used; but if this were done, the stray capacitance and leakage current would be increased. Of course, a coupling capacitor introduces some phase shift at low frequencies.

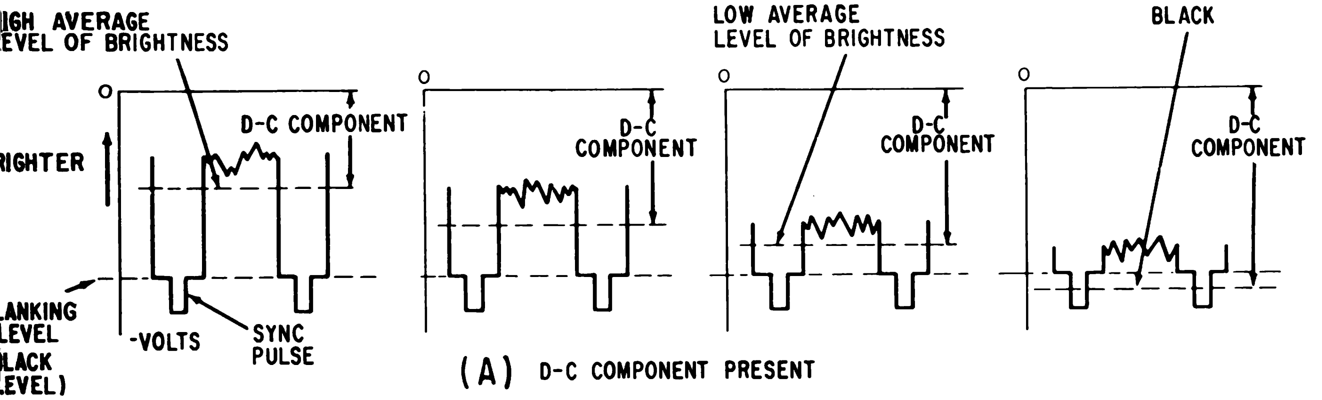
Both the loss in gain and the increase in phase shift at the lower frequencies may be compensated for in part by dividing the load resistor into two parts and bypassing one part with a capacitor. At the lower frequencies the plate load includes both resistors, and therefore the output voltage is higher. At the higher frequencies a portion of the load is effectively bypassed by the capacitor, and the output is proportionately lower.

D-C Restorers

The d-c restorer (or clamper) restores the d-c component of a pulse waveform after this component has been removed by the passage of the waveform through the coupling capacitor in the video amplifier stage. It is necessary to reinsert the correct d-c component at the input of the television picture tube if the correct level of background illumination is to be maintained. Also, if the correct d-c component is not re-inserted, the blanking level will vary (instead of remaining constant, as it should), and retrace lines will appear on the screen during the time the blanking voltage is insufficient to cut off the picture tube during retrace.

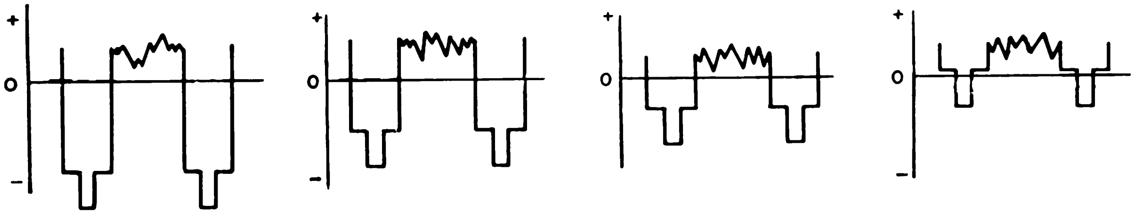
The average brightness of one scanned line may differ widely from the average brightness of another scanned line, as indicated in figure 8-21 (A).

The average d-c component depends on the average brightness of a scanned line. A low d-c component in the negative direction means that there exists a high level of brightness during that line; a high d-c component in the negative direction means that there exists a low level of brightness during that line. The average d-c component therefore establishes the blanking level.



(A) D-C COMPONENT PRESENT

WHEN THE VIDEO SIGNAL PASSES THROUGH A COUPLING CAPACITOR, THE D-C COMPONENT IS REMOVED, LEAVING AN A-C SIGNAL THAT VARIES ABOUT THE ZERO LINE



(B) D-C COMPONENT REMOVED

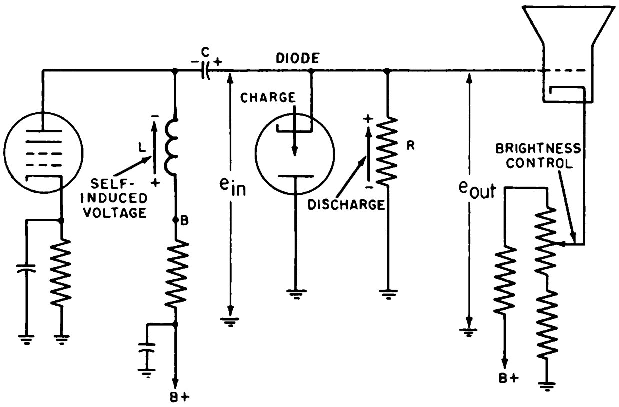
Figure 8-21.—Function of the d-c component in the video signal.

Figure 8-21 (B) illustrates what happens vhen the d-c component is removed by the assage of the video signal through a coupling apacitor. Although the picture tube may be iased so that it is not driven in a positive irection beyond a certain value, nevertheless he blanking level varies and the retrace is ften visible. The background brightness level lso differs from that at the transmitter.

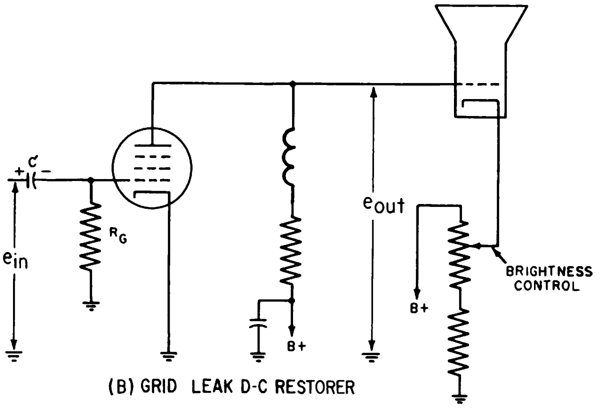
Simplified circuits of two types of d-c estorers are shown in figure 8-22. The function n each case is to restore the d-c component hat was lost when the video signal passed hrough the coupling capacitor of the video mplifier. D-c restoration is accomplished y adding to the instantaneous a-c signal enough -c voltage to bring the blanking voltage to the utoff point.

The action of the d-c diode restorer may e explained in the following manner: Without e diode the input signal voltage has the apearance of that shown in figure 8-21 (B). During the negative portion of the cycle (when the blanking and synchronizing pulses are active) the diode (fig. 8-22 (A)) conducts because its cathode is negative and its plate is positive. This action occurs because the self-induced voltage across L opposes the B supply voltage and exceeds the value between point B and ground. Capacitor C charges rapidly through the diode and has the polarity indicated. The amount of the charge (voltage across C) depends on the strength of the input signal.

During the positive portion of the signal, shown above the 0 line in figure 8-21 (B), the diode cannot conduct, and C (fig. 8-22 (A)) discharges relatively slowly through R. A positive potential, which reduces the bias on the picture tube, is thus applied between grid and cathode during the scan interval between the blanking pulses. During this interval the diode is effectively an open circuit, and the video signal appears across R in series with the d-c voltage supplied by C. The greater the input voltage,



(A) DIODE D-C RESTORER



(B) GRID LEAK D-C RESTORER

Figure 8-22.—Simplified circuits of d-c restorers.

the less the net bias remaining on the grid of the picture tube and the higher the average brightness. Thus the condition existing in figure 8-21 (A), is reestablished.

A grid leak d-c restorer circuit is shown in figure 8-22 (B). The incoming video signal has a negative picture phase, and the d-c component is missing; the output video signal has a positive picture phase, and the d-c component is restored, or reinserted.

The action of the grid leak may be explained simply. There is no fixed bias on the tube, and the grid goes positive whenever a positive pulse is applied. Grid current flows, and C charges rapidly through the conducting grid circuit. If a large pulse is applied, a large amount of grid current flows and a large bias is developed. If a small pulse is applied, a small amount of grid current flows and a small bias is developed. These two actions tend to stabilize the plate current at the same level during the pulses of current; that is, the blanking pulses are lined up at the same level as they were before the d-c component was removed. During the interval between blanking pulses, C discharges slowly through Rg.

It should be emphasized that the bias remains essentially constant (because of the long time constant of C and Rg) during the interval between blanking pulses. If this were not true, the d-c component would be lost.

TELEVISION SOUND SYSTEMS

The sound system of a television receiver is essentially the same as that of an FM receiver. Because FM receivers are described in Basic Electronics, NavPers 10087-A, it is unnecessary to describe them in detail in this chapter. An important difference, however is the system used for IF amplification. There are two systems in use: the split-sound system and the intercarrier-sound system.

SPLIT-SOUND SYSTEM

A simplified version of a split-sound system is shown in figure 8-23. Although a large number of the newer television receivers use intercarrier sound, some sets still employ the split-sound system. In the split-sound system the sound IF is removed at the output of the converter (or from the first video IF) and amplified in a series of sound IF amplifiers.

INTERCARRIER-SOUND SYSTEM

A simplified version of an intercarrier system is shown in figure 8-24. This system is now used in most commercial sets. Its obvious advantage is that the sound is amplified along with the video, which means fewer audio stages are necessary.

The carrier IF in the output of the RF unit is the same as those in the output of the RF unit in the split-sound system. Because the IF stages in the intercarrier system must pass both the picture and the sound IF carrier, the bandpass must be wide enough to pass both of these frequencies.

Although both video and sound IF carrier frequencies (with their sidebands) are amplified

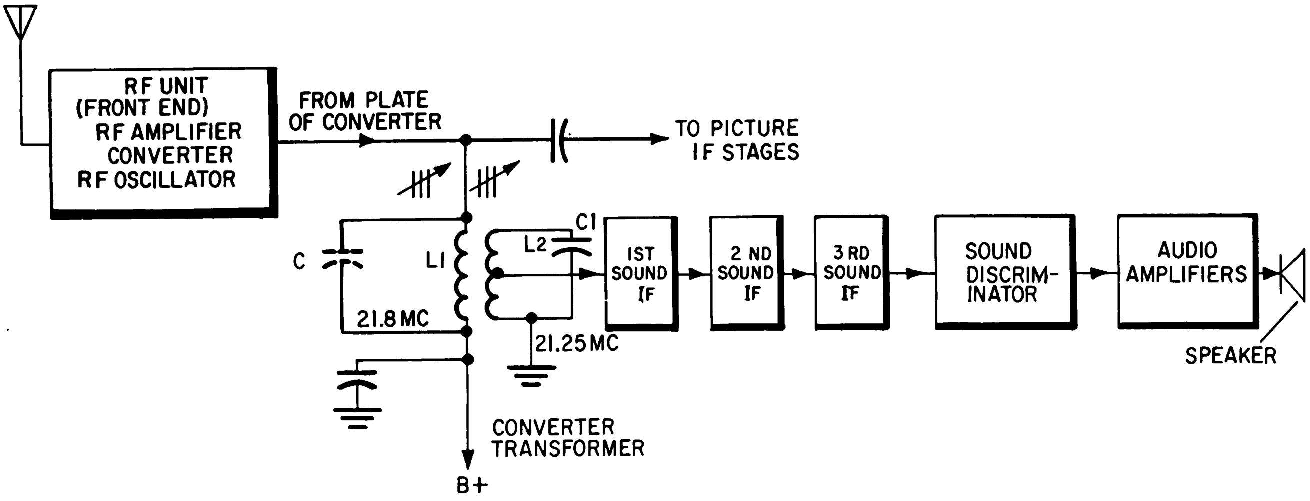


Figure 8-23.—Split-carrier sound system.

in the IF stages, the sound IF is not amplified as much as the picture IF. By keeping the sound IF level much lower than the picture IF level, a 4.5-mc beat note, containing only the modulation of the orignal RF sound carrier, is obtained at the second detector. This beat note is the difference in frequency between the sound carrier IF and the picture IF and, in fact, is the sound IF signal after it has passed the second detector. The difference between the video and sound carrier frequencies forms the basis of the sound IF and is always 4.5 mc.

The 4.5-mc sound IF is extracted, as shown in figure 8-24, from the video amplifier by a 4.5-mc trap. The sound IF then passes through a sound IF amplifier, which also serves as a limiter. The signals is then passed to a ratio detector and to an audio amplifier and speaker.

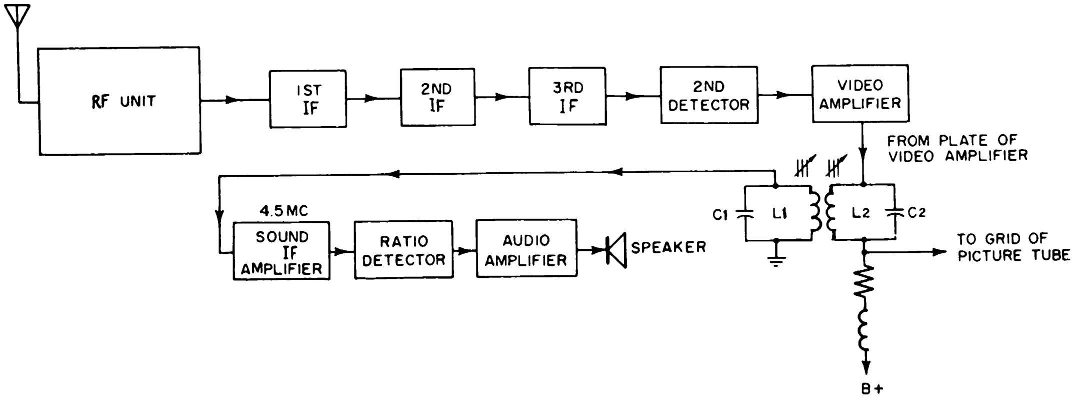


Figure 8-24.—Intercarrier-sound system.

AUDIO DETECTOR

When the ratio detector is used in the sound system of a television receiver, three or more tubes are required for the sound. Even more tubes are required when the discriminator is employed.

For additional economy of tubes, the gated-beam tube is sometimes used as the FM detector in television receivers. (It is also used in FM receivers.) Only one additional tube (output tube) is required in the audio portion of the intercarrier-sound system employing the gated-beam tube because this tube amplifies and detects the signal. A simplified version of the gated-beam tube and the associated circuits is shown in figure 8-25.

The sound IF signal is applied to the grid of the tube by the series-resonant input circuit. This provides some voltage step-up. If a given potential is applied to either the input grid or the quadrature grid, the plate current will not exceed a certain value even if the other grid is made much more positive. On the other hand, if the potential on either of the grids is negative enough, plate current cutoff will occur no matter what

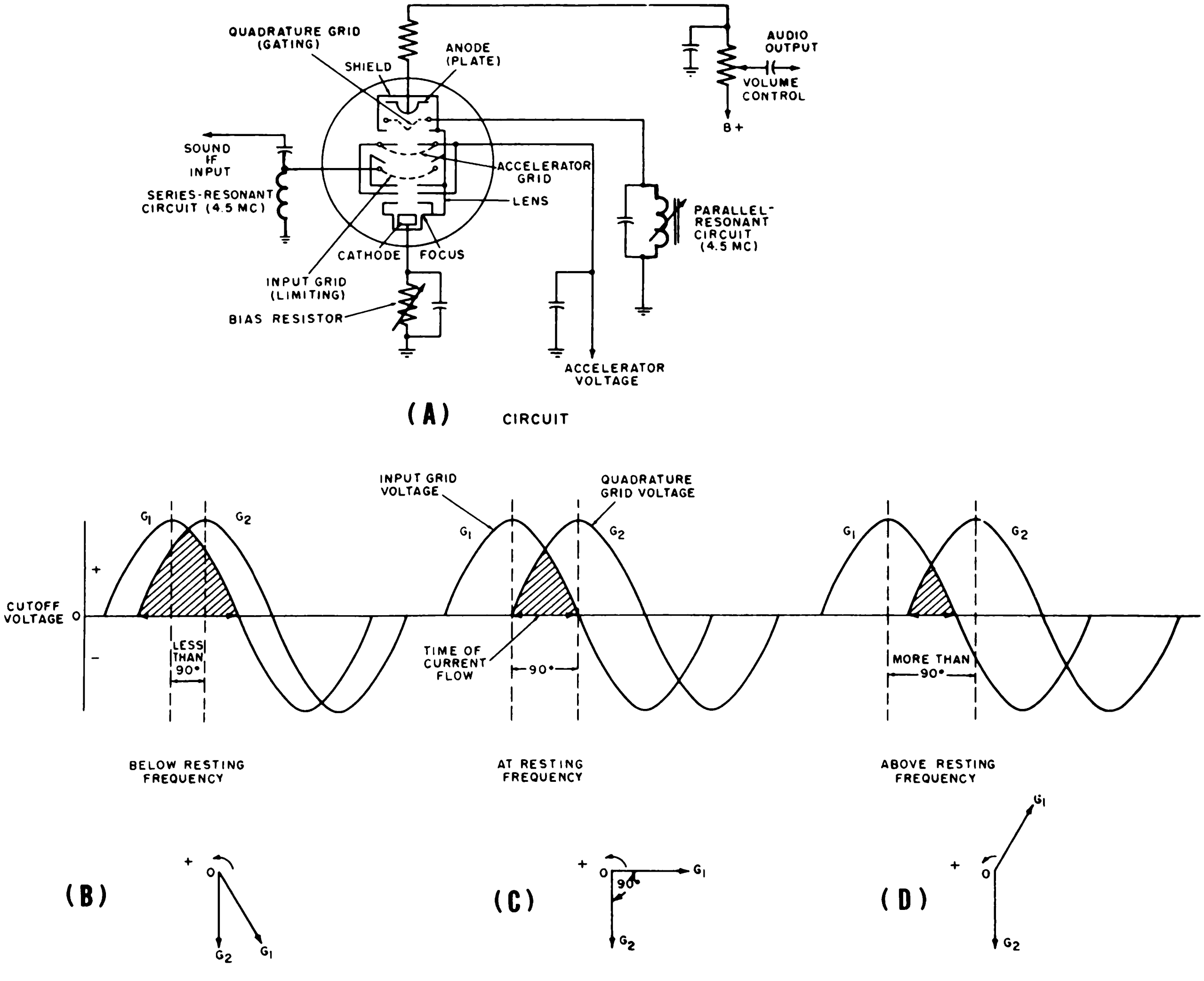


Figure 8-25.—Gated-beam tube and circuit.

potential is applied to the other grid. In any case, plate current does not flow unless the potentials on both grids are above the cutoff value. The amount that an incoming signal is permitted to change the plate current is thus limited.

A parralel-resonant circuit, tuned to the center frequency of the sound IF, is connected between the quadrature grid and ground. This high-Q circuit is actually the heart of the FM detector.

Assume that an unmodulated signal is applied to the sound IF input circuit. A voltage, the net value of which depends on the strength of the signal and the setting of the bias resistor, is applied between the input grid and cathode. Electrons approaching the quadrature grid induce a current in the parallel-resonant circuit. The resultant voltage between the quadrature grid and ground is 90° out of phase with the voltage between the input grid and ground (fig. 8-25 (C)). Therefore, the tube can conduct only when both voltages are above the cutoff voltage.

Now assume that a frequency-modulated signal is applied to the input grid. When the input signal is below the resting frequency, the parallel-resonant circuit becomes inductive. The quadrature grid voltage is less than 90° out of phase with the input grid voltage, as shown in figure 8-25.

When the input signal is above the resting frequency, the parallel-resonant circuit becomes capacitive. The quadrature grid voltage is then more than 90° out of phase with the input grid voltage, as shown in figure 8-25 (D).

Because plate current flows only when there is a positive potential on the quadrature and the input grid, the relative time durations of current flow are as indicated in figure 8-25. The volume control and the capacitor in the plate circuit, in effect, smooth out the current pulses and develop the audio signal voltage across the volume control.

SYSTEM ANALYSIS

The key to effective maintenance is the ability to analyze the complete system in operation, determining how each section affects the other. In troubleshooting a television system, symptoms can be obtained by viewing the picture tube and listening to the sound system. A summary of the overall system operation is the first step in analyzing troubles.

SUMMARY

The objective in television is to convert light reflections from an object into equivalent electrical impulses so that with the help of control and scan circuits the image of the object may be reproduced at the receiver.

The complete details of a picture or object cannot be transmitted (with the system currently being used) simultaneously. They must be sent bit by bit in rapid sequence so that with the aid of persistence of vision the picture may be seen as a whole. This method of transmitting a picture in parts, or bit by bit, is called scanning. (See fig. 7-2.) In the United States, scanning (both in the camera tube and in the picture tube) is from left to right and from top to bottom. In order to avoid objectionable flicker without increasing the horizontal scanning speed, and without increasing the bandpass requirements of the composite TV signal, each of the thirty complete frames that are scanned out each second is divided into two fields. That is, during the first field every other line is scanned, and during the second field the lines missed during the first field are covered. This system of scanning is called interlaced scanning. (See fig. 7-3.) Essentially the same net effect, as far as the viewer is concerned, is obtained by the shutter action in moving-picture projectors.

In one type of camera tube the electron beam, under the influence of the deflection coils, scans across the mosaic, which is composed of minute globules of a light-sensitive compound. The individual globules have charges that are proportional to light incident on them. The electron beam neutralizes the charges, and the resultant instantaneous electron flow from the common backplate of the mosaic through a resistor develops an instantaneous signal voltage. The succession of signal voltages is amplified, and along with the blanking and synchronizing voltages, is used to modulate the video carrier wave.

Blanking voltages are used to blank out the electron beam in both the camera and the picture tubes during the horizontal and vertical retrace times. Synchronizing voltages are injected during the blanking periods to synchronize the horizontal sweeps and the vertical sweeps at the transmitter and the receiver.

Because an image may contain a vast amount of detail, a wide range of frequencies must be transmitted for satisfactory viewing. Therefore, the transmitter and receiver circuits must be capable of passing, without distortion, a wide range (about 4.5 mc) of frequencies.

Although the audio signals are transmitted along with the video signals, the audio and the video systems are essentially separate systems. The video carrier is amplitude modulated and the sound carrier is frequency modulated.

Because the television signals present at the receiving antenna are often very weak, it is necessary to use a high-gain antenna. (See fig. 8-13.) Out-of-phase signals may arrive (after reflection) at the rear of the antenna, and may make the use of a highly directional antenna desirable. Various types of commercial antennas are available for both the VHF and UHF bands. The UHF antennas are smaller, and therefore elaborate arrays that would be too cumbersome at lower frequencies are sometimes used.

Television "front ends" (tuners) have much in common with radio front ends. However, bandpass considerations, wide tuning range, high frequency operation, and reception in fringe areas have introduced design problems. Front ends are composed of an RF amplifier, a local oscillator, and a mixer. (See fig. 8-14.) The cascode amplifier is a popular television RF amplifier. It produces fairly high gain and introduces very little noise. The oscillator and the mixer sections of TV receivers are generally included in spearate tube envelopes in order to achieve maximum frequency stability.

A number of tuning methods are used in TV front ends. Rotary switches that connect the correct inductors and capacitors for the desired channel are often employed. In some systems the "tuned line" is used, and in other the turret tuner is used. The Inductuner, one of the few continuous tuners, tunes over the entire tuning range.

Bandpass requirements vestigial sideband transmission, and the necessity for trapping out undesired frequencies have introduced problems in the design of video IF amplifiers. Stagger tuning is employed to obtain the desired bandpass. In order to avoid overemphasizing the frequencies adjacent to the video carrier, the video IF stages are adjusted so that the video IF falls approximately halfway down on the slope of the video IF bandpass. Resonant trap circuits are used to absorb and dissipate the energy contained in the undesired frequencies.

The video detectors commonly employed are electron tubes or crystal diodes. (See fig. 8-20.) The output of the detector may have positive or negative picture phase, depending on the way the diode and elements of the picture tube are connected.

After the video signal has been rectified in the video detector, it is amplified in one or more amplifiers before it is applied to the picture tube. Because a wide band of frequencies must be passed without discrimination by the video amplifiers, they must be carefully designed. Special high and low frequency compensating circuits must be used to extend the approximate range of frequencies passed from 30 cycles to 4 mc. In other words, frequency distortion must be eliminated as much as possible. In order to pass the required wide band of frequencies, some form of shunt compensation or series compensation or a combination of both is used. Likewise, phase distortion must be eliminated as much as possible. Phase distortion is reduced by the proper design of the coupling circuits.

The d-c component of a pulse waveform must be restored after it has been removed by the passage of the waveform through the coupling capacitor in the video amplifier stage. It is the function of the d-c restorer to reinsert the correct d-c component at the input of the television picture tube so that the correct level of background illumination is maintained. Diode or grid leak restorers are the types often used.

Synchronizing circuits are exceedingly important in TV receivers. These circuits separate the sync pulses from the composite video signal, and in turn separate the horizontal from the vertical sync pulses.

The horizontal sync pulses are used to trigger the horizontal oscillator (a multivibrator or a blocking oscillator) at the correct instant to keep the horizontal sweep of the receiver in step with the horizontal sweep of the transmitter. If the horizontal oscillator does not lock-in properly, the picture gives the appearance of tearing.

The output of the horizontal oscillator is fed to a circuit (for example, a discharge tube), which gives the voltage pulse the proper trapezoidal sawtooth form. The pulse is then amplified and fed to the deflection yoke. It is common practice to utilize the inductive kick due to the horizontal flyback in the output transformer to produce the high voltage for the picture tube. The output transformer has an autotransformer arrangement, which effectively adds the necessary additional inductance. Included in this stage is the damper tube which dampens oscillations and provides boosted B+.

The vertical sync pulses are used to trigger the vertical oscillator (a multivibrator or a blocking oscillator) at the correct instant to keep the vertical sweep of the receiver in step with the vertical sweep of the transmitter. If the vertical oscillator does not lock-in properly, the picture will "roll" downward or "jump" upward.

The pulse from the vertical oscillator is properly shaped, amplified, and fed to the yoke as sawtooth current.

In the intercarrier system, the sound and the video signals are amplified in the same IF system of amplifiers. At the video detector, or in a circuit following the video detector, the sound IF is removed and fed to the sound IF amplifier, which also acts as a limiter. A ratio detector or a discriminator may be used as the FM detector. A gated-beam tube is sometimes used as the FM detector. When this tube is used, the sound IF stage may be omitted. After the FM sound signal has been detected, it is fed to the audio amplifier and the speaker.

UNIT ISOLATION

When troubleshooting a system the first step is to isolate the probable trouble to one major unit. Figure 8-26, which illustrates the major units of the system, shows that the video signal starts at the camera and goes to the control unit. From the control unit the signals are sent to the monitors by way of a cable and then to the receivers via air transmission.

If one video monitor/receiver develops trouble, the first check to make is to observe the other monitors. For example, if the other monitors/receivers are working normally, it can be assumed that the camera unit and control unit are functioning properly. The trouble must be either in the video monitor/receiver or in the connecting cables.

When all monitors/receivers have the same trouble, the trouble must be in some unit that is common to them. In this case the control unit or the camera unit may be the source of trouble. Checking the input to the control unit with an oscilloscope will determine the operation of the camera unit. Correct video signals appearing at the video input jack eliminates the camera unit. This isolates the trouble to the control unit. Procedures contained in the manufacturer's maintenance manual will aid the TD in finding the faulty component.

CIRCUIT ISOLATION

Observing the picture on the receiver/monitor furnishes the TD with valuable symptoms of trouble. The sound system operation is heard through the speaker. The operating condition of practically all other circuits (fig. 8-27) is displayed on the picture tube.

Reviewing the block diagram (fig. 8-27) will show how the operation of the individual circuits are related to the other circuits. The low voltage power supply furnishes voltages for the whole receiver. Trouble in this circuit affects both the video and sound. The received video and sound must pass through the tuner section; trouble in this circuit results in both video and sound trouble. The high voltage supply furnishes the voltages to the picture tube for the picture raster. Trouble in this circuit would affect the brightness of the raster only, while video and sound could be normal. However, in this case the video is present but cannot be seen because the picture tube is not illuminated.

The sweep systems are free running and not dependent upon received signals to start their operation. When the horizontal sweep system starts oscillating, energy is supplied to the high voltage supply circuit and the picture tube is illuminated. If the raster is present, the sweep circuits are operating. If no video (picture) is present, the trouble circuit is one that affects the picture only. Referring to figure 8-27, it can be seen that the video received at the input (antenna) passes through the tuner and then through the video section to the picture tube. If sound is heard, it can be assumed that the tuner is normal. This further isolates the trouble to the video amplifiers.

While it is beyond the scope of this training course to describe all the possible troubles encountered, the examples in table 8-1 illustrate the technique used to isolate a trouble in a complex system into a simple circuit problem. Table 8-1 is based on a typical receiver circuit using intercarrier sound with the sound takeoff circuit in the video system, shown as a broken line in figure 8-27.

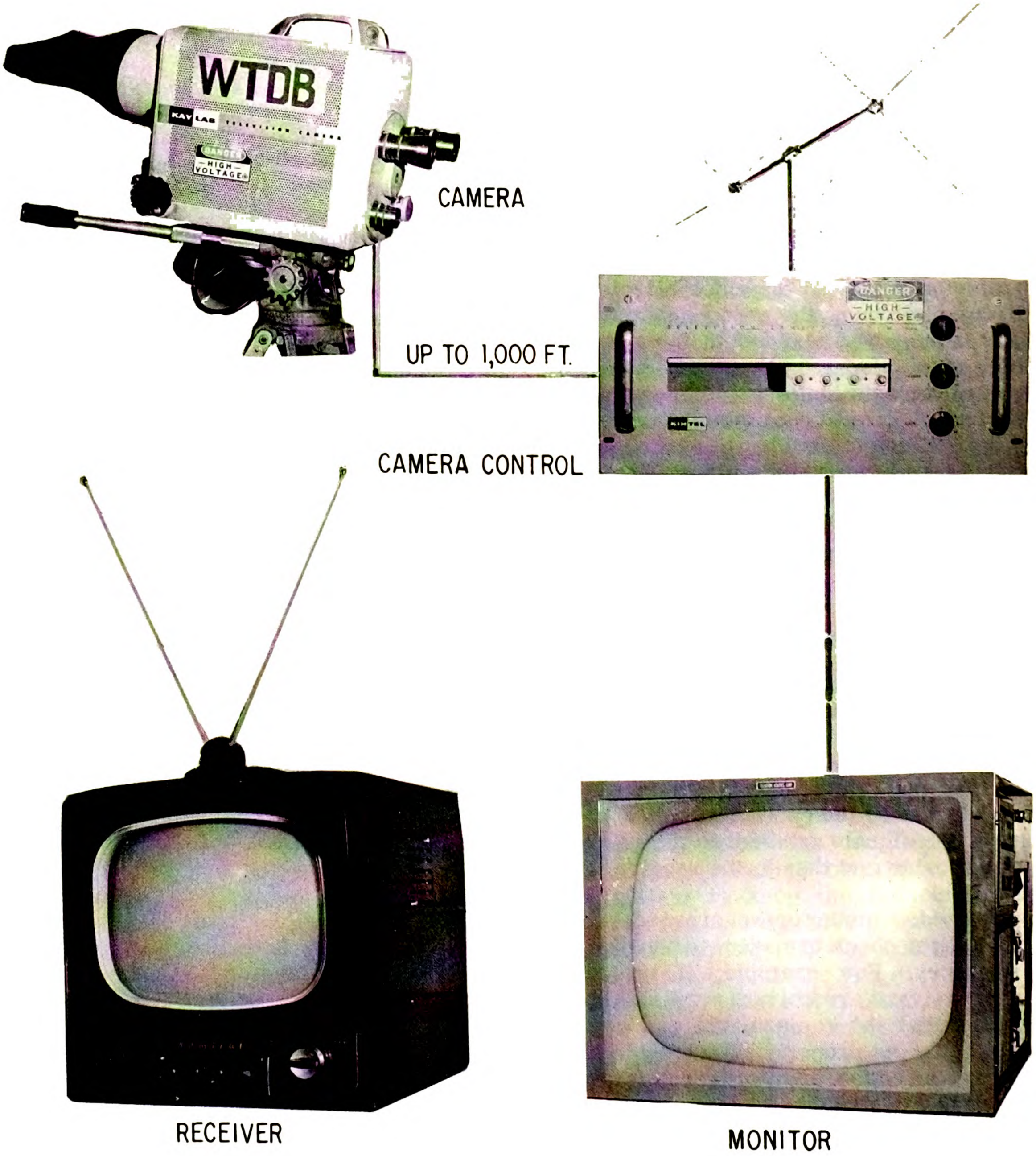


Figure 8-26.—System Components.

Table 8-1.—TV receiver analysis.

Symptom	Analysis
Receiver dead; no raster, picture or sound.	Check powerline into receiver, safety interlock switch, and powerline fuse, if any. Possible failure in low voltage supply. If tube filaments light, receiver has input power.
No sound and no picture, but raster is normal.	Power supplies and deflection circuits are operating normally to produce raster. Trouble is in the signal circuit common to both picture and sound. Check RF tuner, common IF amplifier, and sound detector. Check AGC circuit for excessive negative bias which cuts off the signal amplifiers. Check video amplifier.
Trouble on one channel, but operation is normal on other channels.	Check tuner tubes. Dirty contacts on station selector switch. Incorrect local oscillator frequency.
No brightness or raster on screen. Sound is normal.	Check high voltage circuits and horizontal deflection circuits with flyback supply; check fuse in horizontal output circuit. Picture tube cut off by excessive negative bias. Check picture tube.
Insufficient brightness.	Insufficient high voltage. Excessive negative bias on picture tube. Check low voltages. Weak picture tube. Dust on picture tube and safety glass.
Raster with picture too small, horizontally and vertically.	Low B+ supply voltage. Check line voltage and low voltage power supply.
Raster with picture too narrow, insufficient width.	Insufficient horizontal deflection amplitude. Check horizontal oscillator, amplifier, and damper circuits. Low B+ supply voltage.
Raster with picture too small vertically, insufficient height.	Insufficient vertical deflection amplitude. Check vertical oscillator and output circuits.
Raster with picture tilted with respect to mask.	Rotate deflection yoke.
Raster with picture off center, vertically or horizontally.	Check centering adjustments and tilt of focus magnet.
Trapezoidal raster and picture sides not straight (keystoning).	Defective deflection yoke.
Shadowed corner in raster and picture.	Check focusing magnet and ion trap magnet.
Picture folds over at left or right edges of raster.	Horizontal retrace time too long, or incorrect phasing of retrace with respect to blanking.
Crowding and spreading of picture at left and right sides of raster.	Nonlinear horizontal scanning. Check width, drive, and linearity controls. Weak horizontal oscillator, amplifier, or damper tube.

Table 8-1.—TV receiver analysis.—Continued.

Symptom	Analysis
Crowding and spreading of picture at top and bottom or raster.	Nonlinear vertical scanning. Check height and linearity controls. Weak vertical oscillator or amplifier tube.
Two narrow pictures side by side separated by black vertical bar, but of full height.	The horizontal oscillator frequency is one-half the correct frequency. Check the horizontal AFC and oscillator circuit.
Right half of picture is superimposed on left side.	The horizontal oscillator is operating at twice the correct frequency. Check oscillator circuit.
No picture, normal raster, and normal sound.	The trouble is in the circuit used only for the picture which is the video amplifier in most receivers.
Weak picture with low contrast.	Weak amplifier tubes causing insufficient gain.
Picture rolls vertically and slips horizontally.	Insufficient vertical and horizontal sync. Check common sync circuits.
Picture rolls vertically. Can be stopped but will not hold. Horizontal hold is normal.	Insufficient vertical sync. Check vertical sync circuits.
Picture slips horizontally and tears into diagonal segments. Can be stopped but does not hold. Vertical hold is normal.	Insufficient horizontal sync or trouble is in horizontal AFC circuit.
Picture (video) bends at edge, but raster is normal and straight.	A-c hum in horizontal sync, or the sync is weak.
Picture not clear, insufficient detail, but focus is good. Resolution not good.	Insufficient response for high video frequencies. Bandwidth too narrow in RF and IF amplifiers. High frequencies lost in video circuits. Video detector or amplifier load resistance is too high. (See NOTE.)
No sound. Picture is normal.	Check 4.5-mc sound IF section and audio amplifier section for bad tubes or alinement. (See NOTE.)
Distorted sound, picture normal.	Check FM detector alinement and audio section. (See NOTE.)
Hum in sound only.	The hum occurring only with picture signal present is modulation hum introduced in the 4.5-mc sound IF section. Hum with or without signal is additive hum from the audio section. (See NOTE.)
Buzz in sound.	Check AM rejection circuit and FM detector alinement for balance. If the picture is black and out of sync, the buzz is caused by an overload condition in a common circuit for picture and sound. (See NOTE.)

NOTE: When indications and tests have localized a trouble to misalinement, the manufacturer's maintenance manual should be consulted for the proper alinement procedure. Alinement of TV circuits is a very exacting process and requires special test equipment. Attempting to aline a receiver without the proper test equipment may result in more troubles than were present at the beginning.

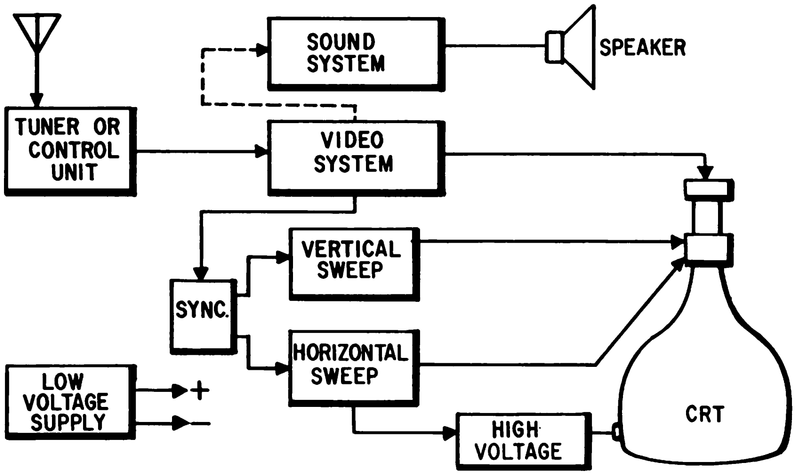


Figure 8-27.—TV receiver/monitor block diagram.

COLOR TV

The contents of chapter 7 and this chapter have been concerned with the pickup, control, transmission, and reception of black and white pictures. This achievement in itself is indicative of modern technology. The addition of color TV has made training aids more realistic in that the trainees see the actual colors of the scene.

It is known that the human eye in association with the brain picks up the reflected light from a scene and imagines the scene as a train of sensations in full color. Normal vision is color vision. Color vision is realistic in that the full psychological and emotional effect of the scene is impressed upon the brain. When viewing a colored painting, the colored objects appear as solid sections of color; but, upon close inspection it is seen that what appeared as solid color is actually individual brush lines. A group of small spots of color would then appear as a solid colored object. This phenomenon is the technique used to reproduce a color scene on the face of a picture tube.

PRINCIPLES OF COLOR

The principles of color presented in the following paragraphs apply specifically to the development of color television pictures. The three primary colors (fig. 8-28) used in television are red, green, and blue. A primary color, when combined with another primary color, produces a different color.

Referring to figure 8-28, it can be seen th the three large circles represent the thre primary colors. In the center where all thre overlap, the color white is formed. The sections where two primaries overlap, another colo is produced. Green and blue produce cya (greenish blue). Blue and red produce magent (bluish red). Red and green produce yellow.

The combining of two primary colors, i proportional amounts, produces the new colo However, when all three colors are combine

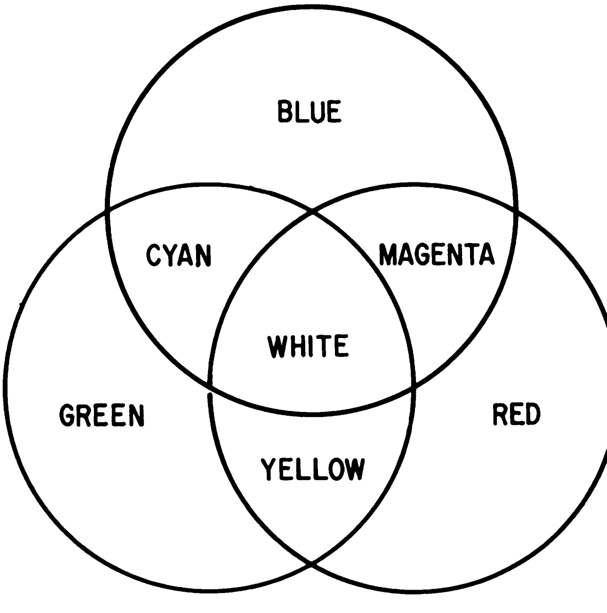


Figure 8-28.—The additive primaries.

as units and in percentage of color, the result is white. Note the following combination:

1. One red unit represents 30 percent red.
2. One green unit represents 59 percent green.
3. One blue unit represents 11 percent blue.

When one unit of green light is combined with three units of red light, the result is orange. By changing the proportions of red and green a variety of colors between red and green can be produced. As the proportion of the primary color mixture changes, the resultant color also changes.

The color by itself is called the hue. Green leaves have a green hue. A red apple has a red hue. Different hues result from different wavelenghts of the light. Red has the longest wavelength; violet has the shortest.

The term saturation indicates how little a color is diluted by white light. The more a color differs from white the greater is its saturation. A weak blue color has little saturation while vivid blue is highly saturated. Saturation is further indicated by the terms purity and chroma.

The brightness of a color as perceived by the human eye is called luminance. The human eye sees brightness increase from blue to a peak at green and then decreases again to red. This apparent response curve is the standard CIE (International Commission of Illumination) luminosity (brightness) curve.

Color resolution is the full three color reproduction of the red, green, and blue primaries. Monochrome (black and white) reproduction is used for the smallest details. For example, in the televised picture of an automobile, the entire body of the car would be in full color. Narrow vertical strips on the frame might be reproduced in two colors, while the outline of the car where it joins the background would be in black and white.

TRANSMISSION

The camera unit used for color pickup is similar to the black and white camera previously discussed. However, in this case, the camera unit (fig. 8-29) has three pickup tubes (one for each of the primary colors). Filters and mirrors are used to direct the right color of light to its respective pickup tube. The output of the camera unit provides a red, green, and blue video signal to the matrix system (a circuit which proportions the primary signals to produce the correct brightness and chrominance colors). The three primary colors are identified as R for red, G for green, and B for blue.

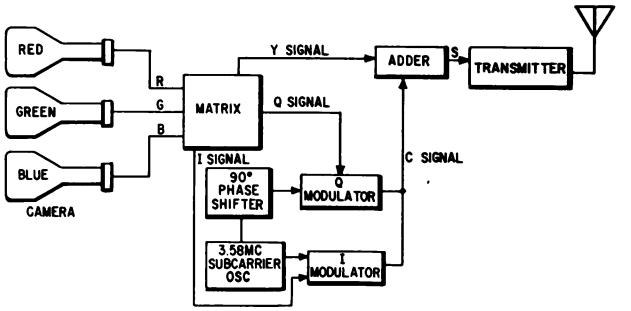


Figure 8-29.—Color TV transmitter, block diagram.

The matrix section is essentially a resistive voltage divider circuit that proportions the primary color signals as required to produce the brightness and chrominance signals. With the red, green, and blue color video voltages as inputs, the three video signal output combinations formed are the following:

1. Luminance signal, designated the Y signal, which contains the brightness variations of the picture information.
2. A color video signal, designated the Q signal, which corresponds to either green or purple picture information.
3. A color video signal, designated the I signal, which corresponds to either orange or cyan picture information.

The I and Q signals together contain the color information for the chrominance (hue and saturation) signal.

The I and Q signals are transmitted to the receiver as the sidebands of a 3.58-mc subcarrier wave (fig. 8-29). A subcarrier is a relatively low frequency carrier wave, within the range of modulation frequencies, which, in turn, modulates the main carrier wave. The subcarrier frequency remains the same regardless of the channel frequency. The output from the subcarrier oscillator is coupled to the I and Q modulators, which also have I and Q video signal inputs from the matrix. The subcarrier is modulated by both the I and Q signals, forming a modulation envelope consisting of the upper and lower sidebands of the subcarrier. The subcarrier is routed through a phase shifter prior to the Q modulator. This causes the Q signal to shift 90° out of phase with the I signal. Modulating the subcarrier makes it possible to broadcast the color information of the I and Q signals simultaneously without loss of identity. Each can be recovered as a separate signal with the proper timing of the transmitter and the receiver. The combined outputs is designated as the chrominance C signal and is routed to the adder (fig. 8-29).

The chrominance signal C (containing the color information) and the Y signal (the luminance information) are both coupled to the adder section, or colorplexer. The colorplexer combines or sums the Y and C signals forming the total video signal S which is sent to the transmitter.

Examination of figure 8-30 will reveal how the combination of color signals will develop the proper hues of colors.

Figure 8-30 illustrates the scanning of one horizonaal line as well as the colors being developed. The signals developed under the white section can readily be seen by following down the column. Adding one unit of R, G, and B together produces the maximum Y (1.0) signal. This results in zero Q, I, and C signals; further resulting in a transmitting signal level of 1.0.

To develop yellow, one unit of red (30 percent) plus one unit of green (59 percent) plus no blue, develops a Y signal of 0.89 (89 percent). Before computing the Q signal, a different set of values for the units of red, green, and blue are established as follows:

1. One unit of red equals 21 percent.
2. One unit of green equals -52 percent.
3. One unit of blue equals 31 percent.

Referring to the yellow column of figure 8-30, it can be seen that one unit of red (21 percent) plus one unit of green (-52 percent) plus no blue develops a Q signal of -0.31. The following set of values is established for computing the I signal:

1. One unit of red equals 60 percent.
2. One unit of green equals -28 percent.
3. One unit of blue equals -32 percent.

The amount of I signal developed for the yellow column is computed: one unit of red (60 percent) plus one unit of green (-28 percent) plus no blue develops an I signal of 0.32.

The chrominance signal C (g, fig. 8-30) is the 3.58-mc subcarrier modulated by the I and Q signals which are in quadrature (out of phase) with each other. Combining the Y, I, and Q signals with blanking and sync pulses produces the colorplexed video signal (h, fig. 8-30). Also inserted on the "back porch" of the blanking pedestal is a synchronizing 3.5-mc color burst. The color burst synchronizes the receiver's color circuits with the transmitter subcarrier frequency.

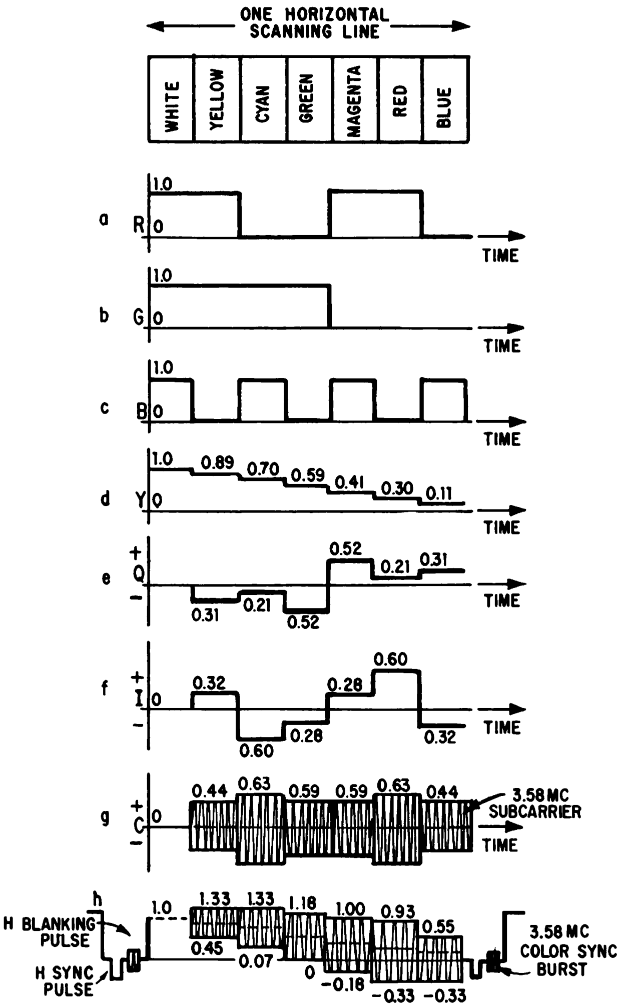


Figure 8-30.—Colorplexed composite video signal.

RECEPTION

The received signals of video (h, fig. 8-30) and sound enter the receiver/monitor just as they did in black and white reception. The same tuner and intermediate frequency amplifiers are used (fig. 8-31). In the video amplifier the signals separate; the Y signal goes to the matrix and the C signal goes to the Q and I demodulators. The 3.58-mc oscillator is synchronized by the

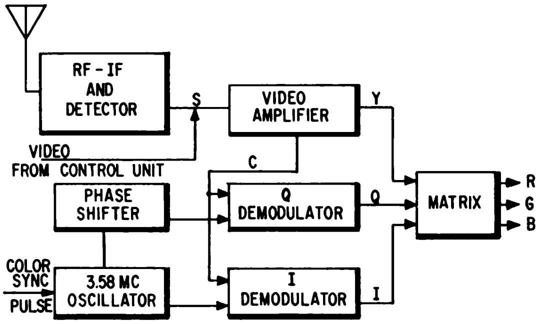


Figure 8-31.—Color TV receiver, block diagram.

color sync burst from the transmitter. The demodulators separate the chrominance C signal into the individual I and Q signals. The matrix circuit forms the original red, green, and blue signals.

The color picture tube (fig. 8-32) is especially made for color reproduction. Three electron guns, one for each color, are employed. The tube's screen consists of small, closely spaced phosphor dots of red, green, and blue. The dots are arranged so that a red, green, and blue dot form a small triangle. The shadow mask provides a centering hole in the middle of the triangle of dots. The convergence electrode causes the three separate electron beams to meet and cross at the hole in the shadow mask.

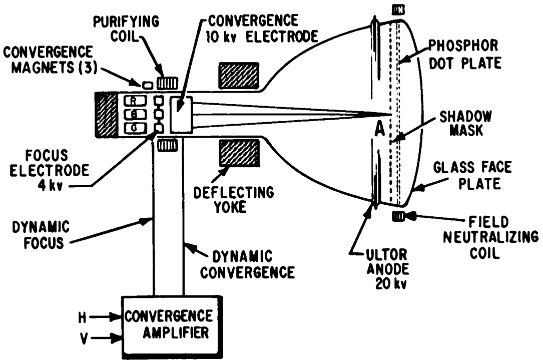


Figure 8-32.—Tricolor kinescope.

Each electron gun is electrostatically focused by a common grid voltage. In other words, each gun has its own electrode but all three are connected together requiring only one grid voltage. The three electron beams scan the screen as controlled by the deflection yoke which is mounted externally around the neck of the tube. As the three beams scan the phosphor screen horizontally and vertically in the standard scanning pattern, the dot trios are caused to light according to the video input signals.

The purifying coil produces a magnetic field within the tube which alines the electron beams parallel to the neck of the tube. Rotating the purifying coil adjusts the electron beams so they strike their respective color dots without striking its neighboring dots. When this adustment is made for the red dots the other two electron beams are alined as well.

The high voltage anode is a metallic ring around the tube. The field neutralizing coil aids color purity at the outer edges of the picture tube. A metal shield, called a mu-metal shield, is placed around the bell of the tube to prevent stray magnetic fields from affecting the electron beams.

The color TV monitor/receiver has many adjustments in addition to those of a black and white unit. The manufacturer's maintenance handbook should be consulted before making any adjustments.

APPLICATIONS

Takeoff and landing of high performance aircraft constitute one of the most critical phases of an aircraft's journey. The pilot must gather many bits of information such as altitude, speed, wind direction, and position. During landing operations he must also know the apparent shape of the runway and its relationship to the horizon during the approach. Because the pilot's information concerning the moment-to-moment potentialities of success during these maneuvers arrives from many different sources, the problem of information assimilation is crucial. In the past the only solution to this problem was extended practice of takeoffs and landings with the actual aircraft.

The operational flight trainer and the instrument flight trainer allowed the pilot to practice cockpit operations, but did not provide visual acquisition of his surroundings. The addition of CCTV systems to trainers such as the

2F23, 2F25, and 2F58 provides the following advantages:

1. Pilots can practice landings and takeoffs without leaving the ground.
2. Procedures for GCA and ILS training can be conducted to final touchdown.

There are two basic methods of visual display: the pilot looks directly at a TV monitor unit mounted ahead of the cockpit and a large movie screen is placed in front of the trainer. (See fig. 8-33).

The video source unit (fig. 8-34) contains a closed circuit TV camera, camera control unit, a mechanical driving system, and servosystems which provide simulation of the aircraft's behavior as follows:

1. Roll.
2. Pitch.
3. Heading.
4. Altitude.
5. Azimuth.

The mechanical belt system consists of framework which supports a continuous neopren belt representing 17,000 feet of runway wit groundspeeds variable from 0 to 200 knots a determined by the aircraft's speed. An approac and runway lighting pattern is appropriately displayed on the continuous belt which is serv driven at a speed which is appropriate to th groundspeed as computed by the trainer. Th approach and runway lights are coated wit fluorescent paint which is activated by a batter of ultraviolet floodlamps.

The TV projector (fig. 8-33) consists of projector barrel, projector tube, and reflecto mirror. The projector is mounted above o beside the cockpit of the trainer.

A large projection screen is placed ahead c the cockpit at the proper distance for the pilot' eyes to view the screen in proper perspective

In some installations a TV monitor unit i mounted directly in front of the cockpit (fig

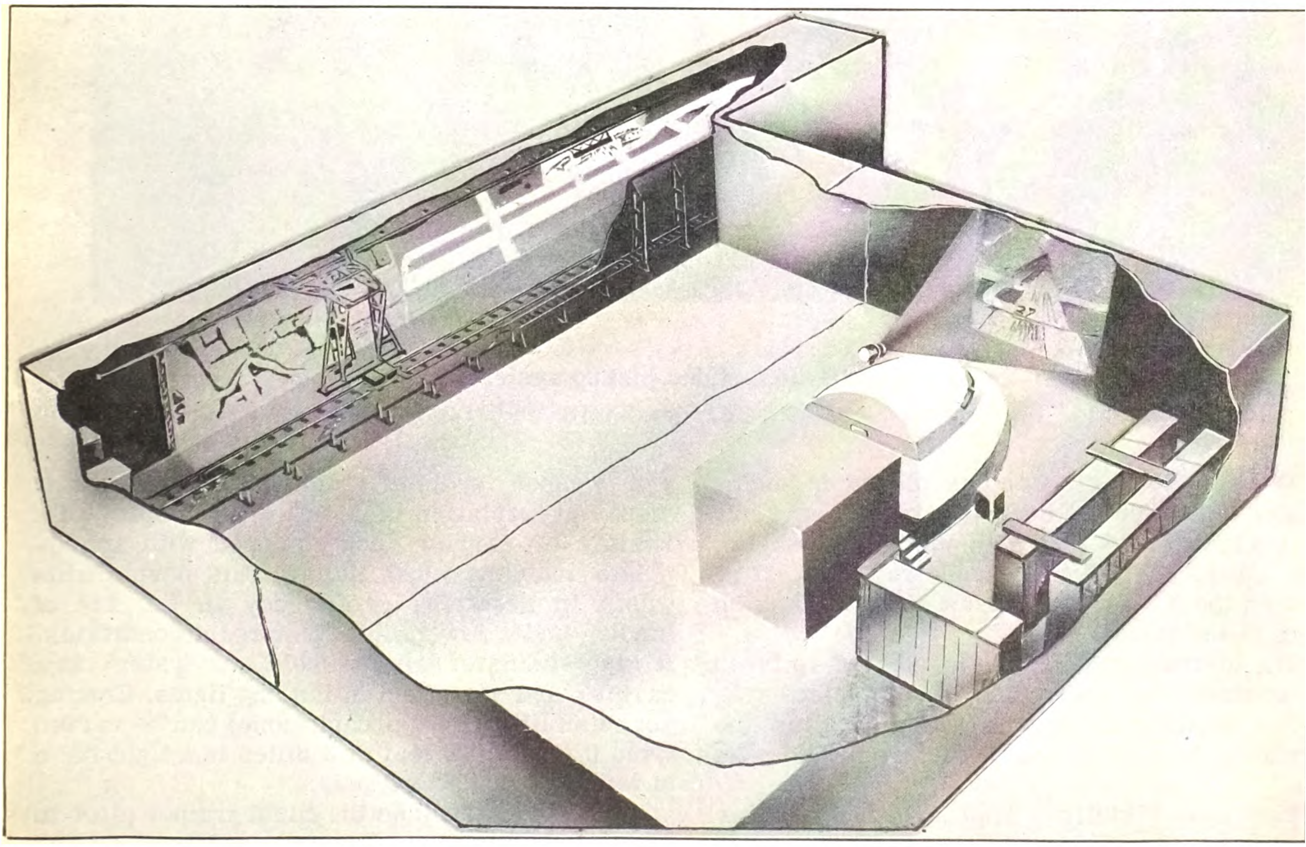


Figure 8-33.—TV attachments for flight trainers.

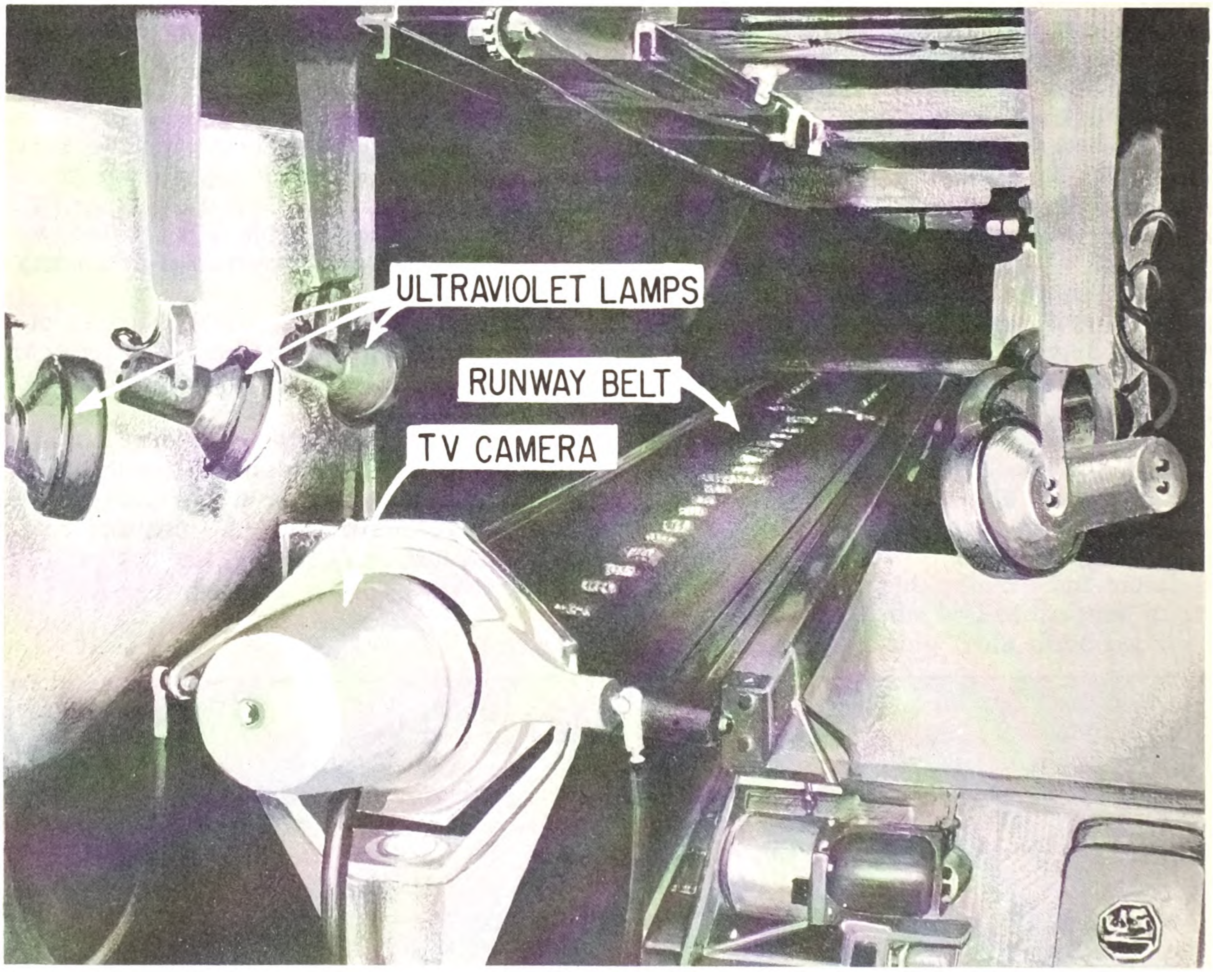


Figure 8-34.—Video pickup system.

8-33). The viewing screen is placed in such a manner that when the cockpit canopy is covering the cockpit the TV screen is the windshield. This allows the pilot to concentrate on what he sees on the TV screen without distraction from lights in the trainer room.

The instructor's console houses the switches and controls for controlling the complete system. A monitor is also provided to allow the instructor to see the same picture as the pilot sees.

The Low-Visibility Approach and Landing Attachment for Flight Trainers, Device 2H53 (fig. 8-35), is designed to be attached to instrument flight trainers, operational flight trainers, and weapon system trainers. It provides a visual presentation of a full color display of a runway or carrier deck equipped with appropriate markings and lights. This device aids pilots in acquiring proficiency in the art of landing under low visibility approach conditions. It also simulates the Fresnel Lens System on a carrier and the effect of landing lights. Ceiling and visibility (in approach cone) can be varied from 0-0 to 1,000 feet at 3 miles in a light haze under night conditions only.

The device enables the flight trainer pilot to simulate either take off from a carrier deck and land at a land base, or take off and return from either base.

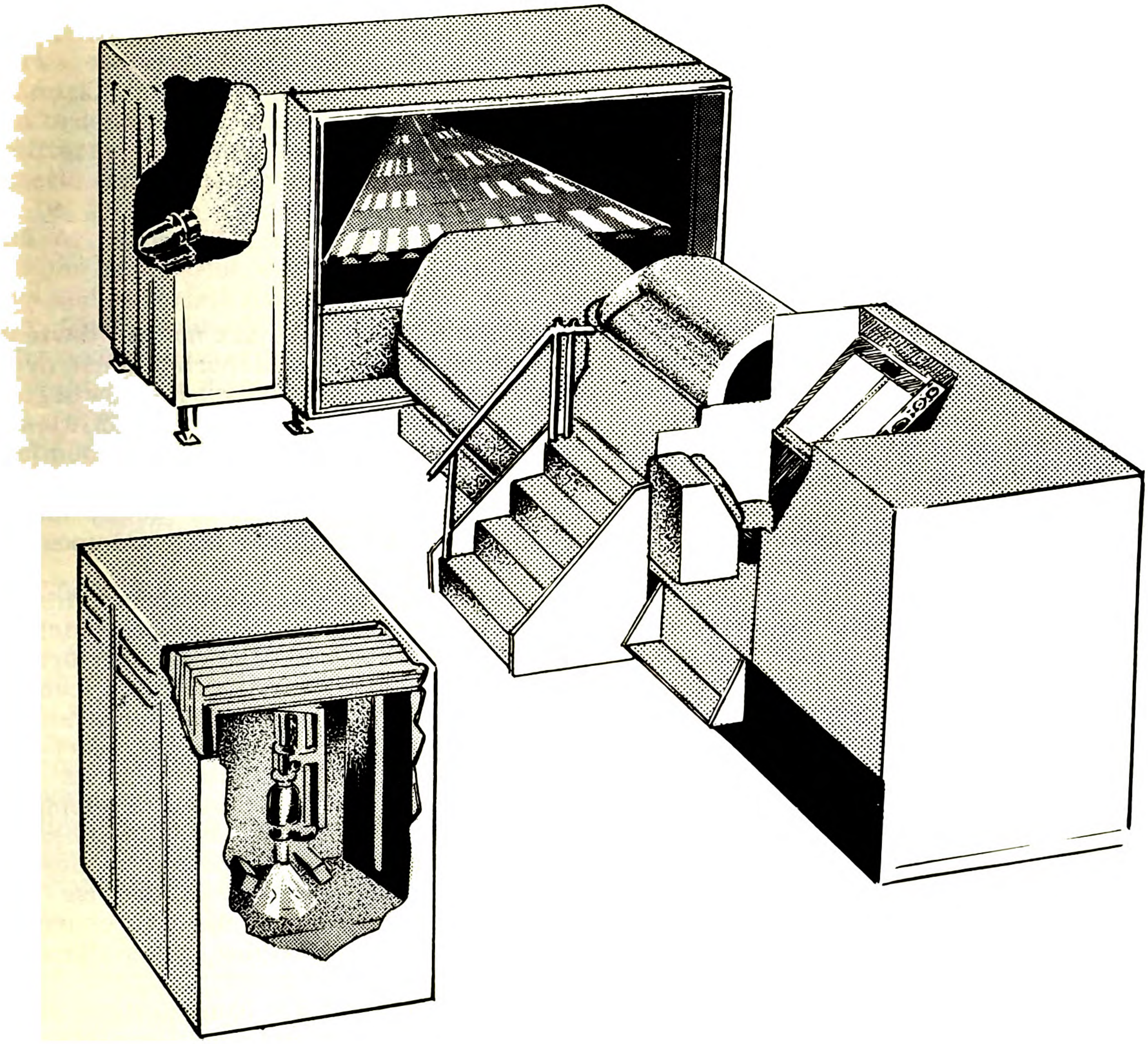


Figure 8-35.—CCTV attachment for trainers, device 2H53.

CHAPTER 9

MAGNETIC AMPLIFIERS

The term "amplification," in general refers to the process of increasing the amplitude of voltage, current, or power. The term "amplification factor" refers to the ratio of output to input. The input signal controls power delivered at the output. The output of a vacuum tube operating between saturation and cutoff is proportional to the signal applied to the grid. It will reproduce this signal with reasonable faithfulness and may be used to amplify voltage, current, and power. As a power amplifier it is limited to comparatively small values of power.

The gas-filled tube, or thyratron is able to handle larger amounts of power than the vacuum tube, but precise control of this power is difficult. The thyratron, by itself, is an all-on or all-off device. When the voltage across the tube reaches a level sufficient to overcome the bias and ionize the gas, the tube goes into conduction rapidly. It then conducts at a maximum rate and continues to do so until the plate voltage drops to the point where it can no longer ionize the gas and the tube cuts off (current ceases to flow). For this reason, thyratrons are usually supplied with a-c plate voltage. This causes the tube to "extinguish" or cut off each time the a-c voltage drops below the ionizing potential. Thus some control over the tube is provided by controlling the ionization point.

The magnetic amplifier combines many of the advantages of both the vacuum tube and the thyratron and in addition contributes several of its own characteristics to advantageous uses in handling large amounts of power. Although their ability to control large amounts of power is an important feature, they are also well suited and frequently used in devices involving signal or voltage amplification. It is usually necessary or desirable to add control currents from several different sources. This is easily accomplished by putting additional windings on the magnetic amplifier core.

Magnetic amplifiers are not new devices by any means, having been reported in use over 50 years ago. Their popularity is just now beginning to be widespread as their capabilities are realized. A magnetic amplifier is essentially a device which controls the a-c reactance of a coil by utilizing a d-c signal to modify the permeability of the magnetic material upon which the coil is wound.

In the early stages of development this basic idea was incorporated into devices which were usually designated as saturable reactors; they were used to control large electrical loads such as theatrical lighting and electric furnaces. However, the saturable reactor, the heart of the magnetic amplifier, was limited in its ability to control the load until the recent development of improved magnetic materials and efficient metallic rectifiers. The utilization of these improved materials resulted in the use of the saturable reactor in more elaborate circuits and led to the distinguishing term "magnetic amplifier."

Many different trade name devices, such as self-saturating magnetic amplifiers, Magamps, Transductors, and Amplistats, have been used to identify the more elaborate saturable reactor circuits. However, the term magnetic amplifier is used in this chapter to identify all amplifying systems which utilize the saturation of a magnetic core for the purpose of control. It is felt that this is the most popular of all terms used at the present time.

The advantages of the magnetic amplifier are principally based on the fact that it is a completely static device. With the exception of the rectifiers used, its mechanical construction is comparable to that of an iron-core transformer. There are no contacts, moving parts, filaments, or other features which account for most of the failures associated with other types of amplifiers (except for those using transistors). The need for frequent inspection and maintenance is reduced to a minimum. The life of the magnetic amplifier is virtually indefinite, and it is especially suited for installations where there are adverse operating conditions, such as vibration and shock.

In order to understand the theory of magnetic amplifiers, a knowledge of magnetism and magnetic circuits is necessary. This information may be found in Basic Electricity, NavPers 10086-A, chapter 7. In addition, chapter 18 of the same publication discusses the basic principles and materials found in magnetic amplifier usage. These subjects are reviewed here only to the extent necessary for continuity. It is the intent of this discussion to build upon these basic considerations and develop the subject of magnetic amplification in greater detail.

REVIEW OF PRINCIPLES

INDUCTANCE

Basically, the magnetic amplifier is nothing more than a controlled variable inductance in series with an a-c power source and a load. It may be recalled that any coil possesses a property of electrical inertia called inductance. The inductance of a coil may be increased by providing it with an iron-core magnetic circuit. The inductance of coils with magnetic cores may be determined with fair accuracy by the following formula:

$$L = \frac{1.256N^2A\mu \times 10^{-8}}{\ell}$$

L = Inductance in henrys
N = Number of turns
A = Area of core in square centimeters
μ = Permeability of magnetic material
ℓ = Length of core in centimeters

Permeability is a measure of the relative ease with which flux flows in a material. The permeability of air is one (1). The permeability of the core of a coil can be increased if the air is replaced by some type of ferromagnetic material such as iron or steel. By observation of the preceding formula, it can be seen that if the permeability (μ) is increased by 1,000 when the iron core is inserted, the inductance will be increased 1,000 times over the inductance of the same coil with an air core.

Figure 9-1 shows a simple magnetic amplifier in which the iron core is mechanically moved in and out of the coil to vary the inductance and hence the inductive reactance of the c When the iron core is completely within coil, the inductance of the coil is maximu Therefore, the voltage drop across the ind tance is maximum, reducing the voltage acr the load resistor R_L to a low value. Howev removing the core from the coil lowers inductance of the coil (hence the impedance the circuit), decreasing the voltage across inductance and increasing the voltage acr the load to nearly 115 volts. In effect, this the operating principle of a magnetic amplifi Since it requires relatively few watts of pov to move the core within the coil, which in t can control perhaps several horsepower, device is an amplifier.

MAGNETIZATION AND PERMEABILITY CURVES

Although the mechanical arrangement j described is effective, control of the pern ability of the coil core is normally obtained saturating the core with a relatively sn amount of d-c or properly phased a-c volta An unsaturated core provides a relatively h impedance to the circuit. A saturated co however, acts similar to an air core, offer practically no impedance except for the low resistance of the coil.

When current flows through a coil, a ma netic force is set up across the coil, the intens of which depends upon the amount of curr flowing through the coil. This force in a ma netic circuit may be compared to the volta of an ordinary electric circuit. The magne motive force sets up a flux about the co which is comparable to the current of an ordina circuit and has a density which depends on reluctance of the core of the coil. The co reluctance, which may be compared to resistance of an electric circuit, has a va which depends on the material forming the co The reluctance of an air core remains const regardless of current. This results in an crease of flux density which is proportional the increase in both current and magne motive force.

When a magnetic substance makes up core of a coil, the reluctance is no longer co stant, regardless of current. Instead, as a cu rent begins to flow, the reluctance is very l and the flux is very high compared to t existing in an air-core coil under similar co ditions. With an increase in current, the relu tance gradually increases and the rate-of-f

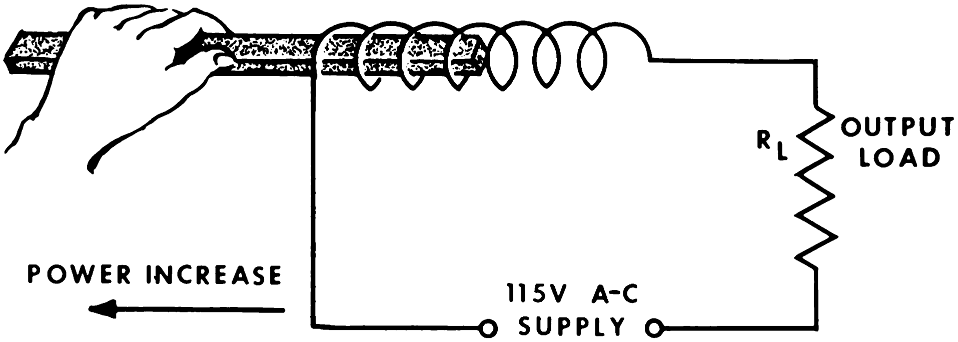


Figure 9-1.—Varying coil inductance mechanically.

increase is reduced. After the current reaches a certain value, which depends on the core material used, the reluctance increases very rapidly until its value approaches that of air. In this region, around point b in figure 9-2, any further increase in current will produce no appreciable increase in flux. This condition is known as saturation.

As previously stated, an iron-core coil that is saturated acts similar to an air-core coil for it offers practically no impedance to changes in current except for the low d-c resistance of the coil. This stems from the fact that the inductance of a coil is proportional to its incremental permeability, which is the ratio of a small change of flux density, ΔB, over a correspondingly small change in magnetizing force or ampere turns, ΔH. (Incremental $\mu = \Delta B / \Delta H$.)

This can be graphically shown by considering a typical magnetization curve, such as that shown in figure 9-2. The flux density, B, is shown in kilogausses and the magnetizing force, H, is shown in oersteds which are proportional to ampere turns. The inductance of the coil is proportional to the rate of change of flux density, B, with respect to magnetizing force (ampere turns), H. It will be seen that in the region of the curve around point a, a small change of ampere turns, ΔH, will produce a large change of flux density, ΔB. This represents the unsaturated condition of the coil, and therefore its inductance is large.

In the region of the curve around point b, the same small change of ampere turns, δH will now produce only a very small change in flux density, δB. This represents the saturated condition of the coil and its inductance in this region is very low.

An application of the basic saturable reactor may be found in a special type of filter choke that is often used in power supplies where the current drain varies considerably. They are called swinging chokes and are designed to operate on the portion of the curve between point a and b. For low values of current, their inductance values are quite high. For high values of current their inductance values are low since the core has become saturated.

The airgap in the swinging choke is much smaller than in the ordinary filter choke and, consequently, the total reluctance of opposition to the magnetic lines of force through the core is small. This permits the choke to become saturated for high values of current. This type of choke has special applications in circuits where the direct-current variations are quite large, since it has been found that they give better direct voltage regulation with varying amounts of direct current. That is, the voltage drop across the choke remains nearly constant even though the amount of current varies over a wide range.

The magnetic amplifier works on the principle that varying the average magnetizing force will vary the inductance. Referring again to figure 9-2, the curve from the origin to the region below point c is quite steep but approximately straight. The inductance in this region is therefore high but constant, that is, given changes of ampere turns will produce high but constant changes in flux density. Operating the coil in this region will therefore produce little or no

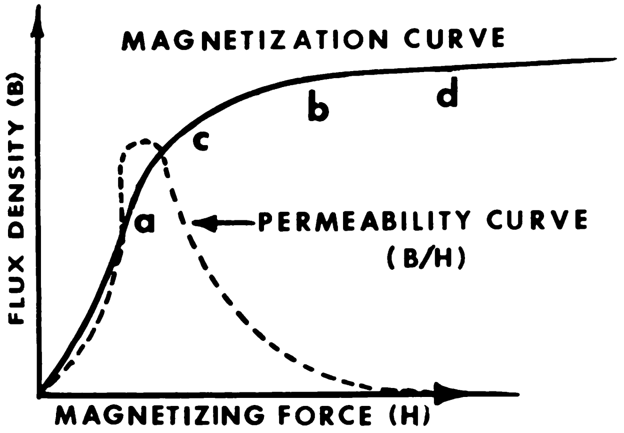


Figure 9-2.—Magnetization and permeability curves.

change in inductance for changes in ampere turns and no amplifier action will result.

The region of saturation around point b is likewise relatively flat, so that the inductance around this region is very small and changes very little with changes in ampere turns. Operation of the coil in this region will likewise be unsuitable for amplifier action.

In the curved or nonlinear portion of the curve around point c, the inductance changes quite rapidly with small changes of ampere turns; that is, the rate of change of flux density with respect to ampere turns is large. This region is the desired operating region of the coil for magnetic amplifier action because small changes of average ampere turns produce large and significant changes of inductance, therefore producing high gain.

It is possible to derive the permeability curve for the magnetization curve shown in figure 9-2 since the ratio B/H is the slope of the magnetization curve. This permeability curve is represented by the broken line in the figure. It clearly shows that the permeability is low for small and for very large values of magnetizing force and is rather high for intermediate values of magnetizing force. The inductance of a coil can be varied by altering the magnetizing force. Figure 9-2 shows that as the magnetizing force is altered the permeability is varied, hence the inductance is also varied.

Removing the iron core physically, as shown in figure 9-1, does not actually control the effective permeability of the magnetic mat
since the core is actually replaced by ai
most modern applications, the saturation me
is used. This not only simplifies the installa
but permits a much higher speed of respo
eliminates mechanical moving parts, and
siderably widens the range of application.

BASIC MAGNETIC AMPLIFIER

The basic circuit for controlling the
power by means of a control winding is il
trated in figure 9-3. Both windings are
common core; the primary is usually refe
to as the control winding.

The primary winding is supplied with a
source for control purposes. A potentiomet
connected in series with this circuit and is
to control the amount of current flow. This
rent flow will establish a unidirectional
in the core at a level depending upon the am
of d-c magnetizing force. The second windi
connected in series with an a-c source an
load, which is shown as a lamp.

Changes of current through the control w
ing correspond to variations in magnetic
intensity (ampere turns). Referring to figure
these variations over the portion of the c
between the origin and point a will produce l
or no change in inductance or permeability
to the nearly straight characteristic of the cu
In order for these changes in current to pro
changes in inductance, they must take plac
the curved portion, or knee of the curve.
means that sufficient current must flow thr
the control winding to place the operating
at the knee, such as at point c. This is
similar to setting the operating point of a vac
tube by means of bias.

With the coil operating on the knee of
magnetization curve, a small increase of cur
through the control winding will lower the in
tance of the coil, or permeability of the c
because the magnetization curve's directio
slope is moving toward a horizontal direc
As a result, the a-c reactance of the load win
is decreased. The decreased impedance o
load circuit will then allow a larger curre
flow, thereby increasing the power devel
across the load. With the core comple
saturated, the load winding reactance d
to nearly zero, leaving only the resistanc
the copper wire to impede the flow of cur
Under this condition, the maximum supply v
age will be applied to the load; thus the l

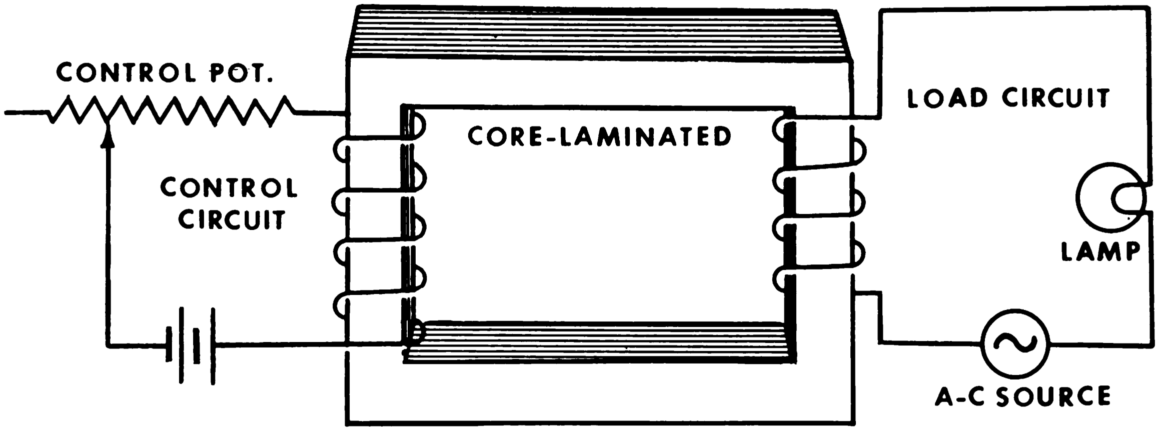


Figure 9-3.—A basic magnetic amplifier.

will be brightest. Conversely, decreasing the current through the control winding will increase the reactance of the load coil, thereby decreasing the power developed across the load.

In the region between the origin and point a on the curve in figure 9-2, the core permeability (hence coil inductance) is maximum, resulting in minimum load current and, consequently, minimum output power. Since the reactance of the load coil winding has been changed by varying the degree of core saturation, the device is referred to as a saturable reactor. The following rule will apply to any saturable reactor or magnetic amplifier: a control current which tends to saturate the core will increase the output of the amplifier.

IMPROVED MAGNETIC AMPLIFIER

The basic magnetic amplifier circuit shown in figure 9-3 is very inefficient because of transformer action between the two windings. The alternating flux from the secondary will induce a voltage into the control (primary) winding. If the control winding has a large number of turns, the voltage may become excessive and may even break down the insulation.

Another reason why this form of magnetic amplifier is seldom used is the fact that the control winding would act as a short-circuited secondary. This would dissipate a considerable amount of a-c energy that is applied to the controlled winding. It is possible to prevent this loss by inserting an isolating impedance, in the form of an inductance, in series with the control winding. Another method of preventing this loss is by utilizing a three-legged core. This method is described in detail.

THREE-LEGGED CORE

The transformer action previously mentioned would also cause an oscillating flux in the core and the usual B-H hysteresis loop of the core material would be traced out during one full cycle of the a-c source voltage as in transformer operation. In order for this circuit to function as an amplifier, sufficient d-c magnetizing force is required to counteract the a-c flux, and an additional amount of d-c magnetizing force is needed to set the operating point.

A much more satisfactory arrangement for a saturable reactor is shown in figure 9-4. This figure shows a three-legged core having an a-c winding on each outer leg connected in series and the d-c control winding on the center leg. In the center leg of a saturable reactor of this type, any alternating flux produced by one of the a-c coils is balanced by the flux produced by the other a-c coil. This is true only when both a-c coils have an equal number of turns and are connected either in series or parallel such that the flux fields produced by the two coils oppose each other through the center leg. This is shown by the dotted lines in figure 9-4.

Since these forces are opposite and equal, they do not pass through the center leg but join

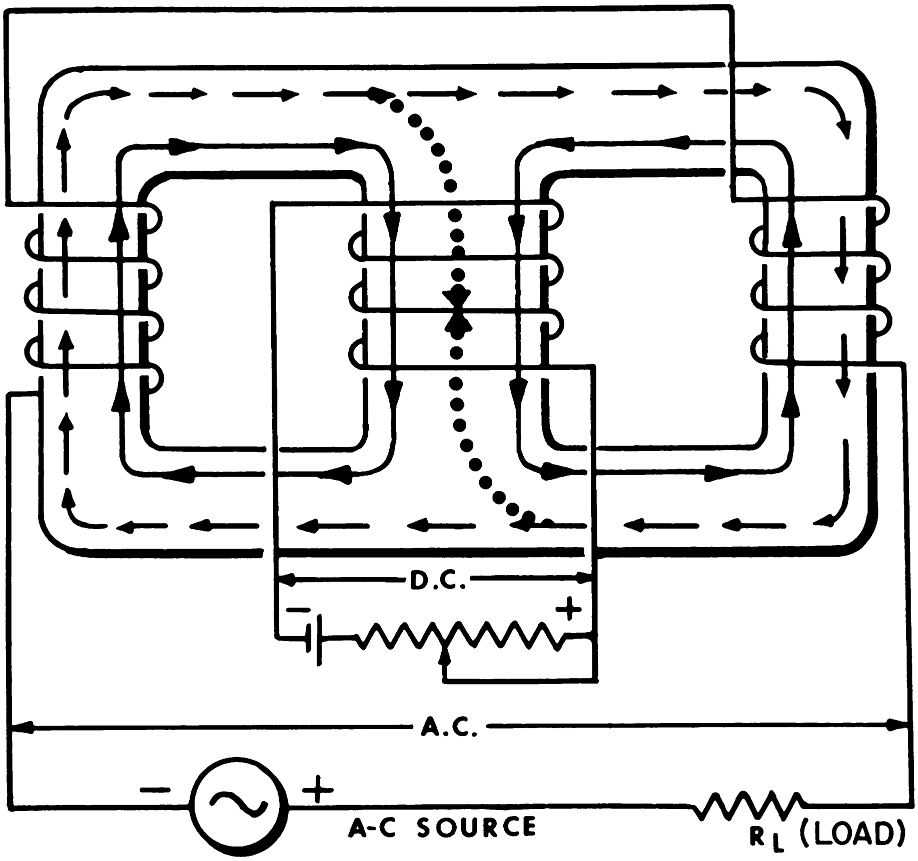


Figure 9-4.—A magnetic amplifier with three-legged core.

in a common path through the outer legs of the core. This is shown by the broken lines in figure 9-4. The figure also shows that the current through the d-c winding on the center leg of the core produces a magnetic flux as indicated by the arrows on the solid lines. The flux lines are caused by the direct current flow in the paths, as shown, and magnetize the entire core. Although the d-c coil is used to magnetize the cores of the a-c coils, no a-c voltage is induced into the control coil when a three-legged reactor is used.

During operation, variation of current in the control coil will vary the magnetization of the core. As has been shown previously, when the magnetizing force is altered, the permeability of the core is varied and, in turn, the inductance of the a-c coils is also varied. In other respects the three-legged magnetic amplifier functions similar to the basic circuit.

As mentioned previously, the a-c coils can be connected either in series or parallel. The series-connected a-c coils offer the advantages of higher voltage gain and faster response characteristics. The parallel-connected a-c coils are capable of handling loads with medium to high current consumption as may be required by large servomotors. The time of response is longer for the parallel windings; however, this is discussed later in the chapter.

Half-wave Rectifier

Another improvement to the basic magnetic amplifier is the use of half-wave rectifiers. Chapter 18 of Basic Electricity, NavPers 10086-A, contains a circuit which includes their application. However the discussion which follows is fundamental to magnetic amplifier circuits as found in training devices.

The type of magnetic amplifier shown in figure 9-3 is relatively inefficient. This is true because the load supply voltage, which is a.c., will create a sinusoidally varying flux which will flow through the core in one direction during one-half of the cycle and in the opposite direction during the other half. Thus, half of the time the flux created by the load current will impede the d-c control winding flux and the other half of the time it will aid this flux. This will shift the operating point of the amplifier from the origin (fig. 9-2) to a point of the curve whose abscissa (horizontal coordinate) corresponds to the peak value of ampere turns, back to the origin, and along a similar curve in the negative direction. In other words, the operating point of the amplifier will trace out a hysteresis curve such as is shown in figure 9-5. Because the amplifier cannot operate in this manner, the oscillating flux must be bucked or counteracted and then a directional flux must be added to partially saturate the core or place the operating point on the desired portion of the magnetization curve.

In order to produce sufficient flux to balance out the oscillating flux caused by the a.c. in the load winding, the ampere turns applied to the control winding would have to equal the ampere turns of the load winding. Then sufficient extra ampere turns would have to be applied to the control winding to set the operating point at the desired place on the magnetization curve. It is obvious then that this would be a very inefficient amplifier because the ampere turns required by the control loop would be greater than the ampere turns in the load circuit.

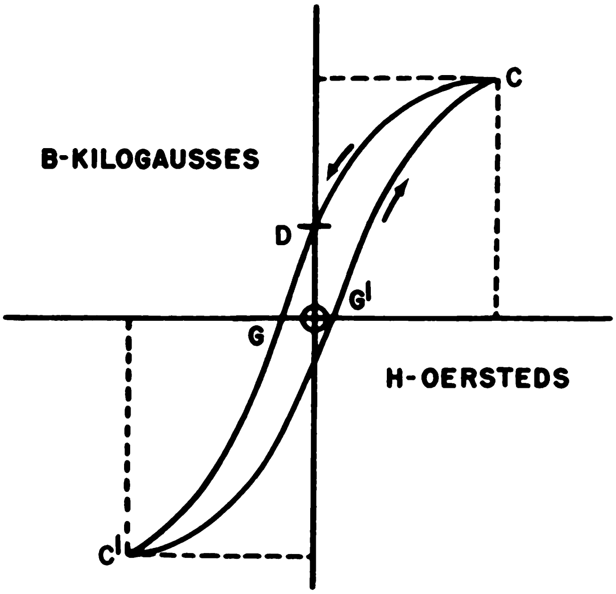


Figure 9-5.—Hysteresis loop.

A more efficient magnetic amplifier utilizing internal feedback is shown in figure 9-6. A half-wave rectifier has been inserted in the load circuit allowing current to pass in one direction only. This unidirectional load current eliminates the oscillating flux caused by the a.c. in the load circuit. Thus, the load current assists the control winding current in saturating the core. A more efficient amplifier is thus provided since less control power is needed for a given amount of control. In this figure the control circuit is so arranged that the magnetic flux resulting from the control current may either aid or oppose that resulting from the load current.

A brief explanation of the self-saturating half-wave magnetic amplifier is possible by using the magnetization curve shown in figure 9-7. This curve has been drawn with the effect of hysteresis neglected. Position a on this curve represents the condition of the control flux when the potentiometer in figure 9-6 is set at the positive end. Under this condition the control current produces a flux which is in opposition to the flux created by the load current. If the amplitude of the alternating current is such that it varies the core flux along the magnetization curve from point a to point d the impedance of the secondary remains large and the voltage drop across the load will be approximately zero.

The relation of the applied voltage and load current for this type of operation is represented by a in figure 9-7(B). When the potentiometer is moved toward the negative end to the position where current still flows in the same direction but of less amplitude so that the control flux is at point b on the curve, the rectified alternating current will now vary the core flux from point b to point e. Under these conditions partial saturation of the core is achieved, resulting in a low voltage waveshape as shown at b in figure 9-7(B). As the potentiometer is moved further toward the negative end, the initial flux density in the core (no load winding flux) is nearer saturation so that the inductance of the controlled winding is reduced earlier in the half cycle and larger values of load current flow. This is shown by c, d, and e in figure 9-7(B).

Effect of Hysteresis on Operation

Up to this point, in order to simplify the introduction to magnetic amplifiers, the effect of hysteresis has been neglected. In order to fully understand the operating characteristics of

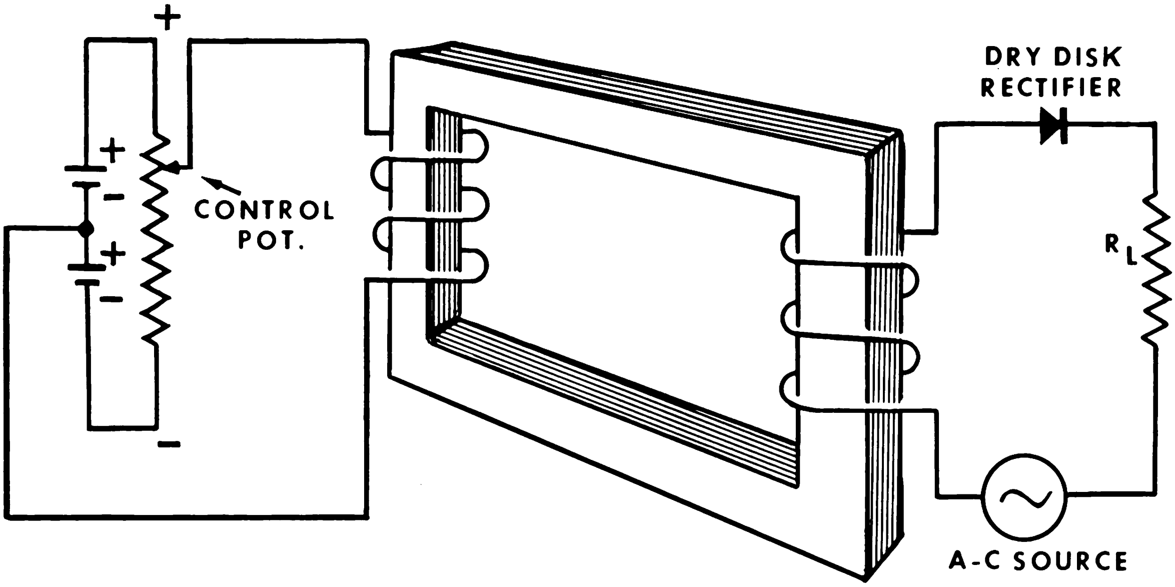


Figure 9-6.—Magnetic amplifier with half-wave rectifier.

magnetic amplifiers, it is important to know how these characteristics are affected by the shape of the hysteresis loop.

The curve in figure 9-8(A) represents a typical rectangular shaped B-H curve; the curves in (B), (C), and (D) show the operation for various amounts of control action.

Further use of figure 9-6 is made in explaining the effects of hysteresis. This circuit actually has two distinct periods of operation. The period during which the rectifier conducts is known as the "operating period"; the other half-cycle of the a.c. is known as the "control period."

In the explanation of the effect of the hysteresis loop of figure 9-8(A), assume that control current is zero and that the load winding current is of such amplitude that it will saturate the core during peak conduction. During the first operating period, conduction through the load winding will cause the core flux to build up along the dotted line from the point of origin, o, to the point of saturation, a. At the end of this period, the flux level in the coil returns to point b rather than to zero because of the retentivity of the core. This is called the remanence point in magnetics and leaves the core in a magnetic state, similar to a permanent magnet. Thus, with no control current the core flux will remain at point b and during each positive half-cycle, the core will saturate immediately. Under this condition the load current will be maximum, for no control is exercised.

Figure 9-8(B) shows the action when a small control current is added. The operation during the first half-cycle is similar to that just described in connection with figure 9-8(A), but during the second half-cycle (control period), the flux will reset from point b to point c. This occurs because the direction of the control flux in the core is opposite to that of the operating flux.

This positioning of the residual flux is called "resetting." During the next half-cycle the flux starts increasing from point c in the figure and a small period of this half-cycle is used before the flux reaches saturation at point a. At this point the core is saturated and the rectifier is in maximum conduction for the remaining part of this half-cycle. At the end of the operating period the flux returns to point b where the control period starts and resets the flux to point c where the cycle starts repeating itself. The output for this condition is shown as the shaded portion of the waveform of figure 9-8(B). Figure 9-8(C) and (D) shows the operation for

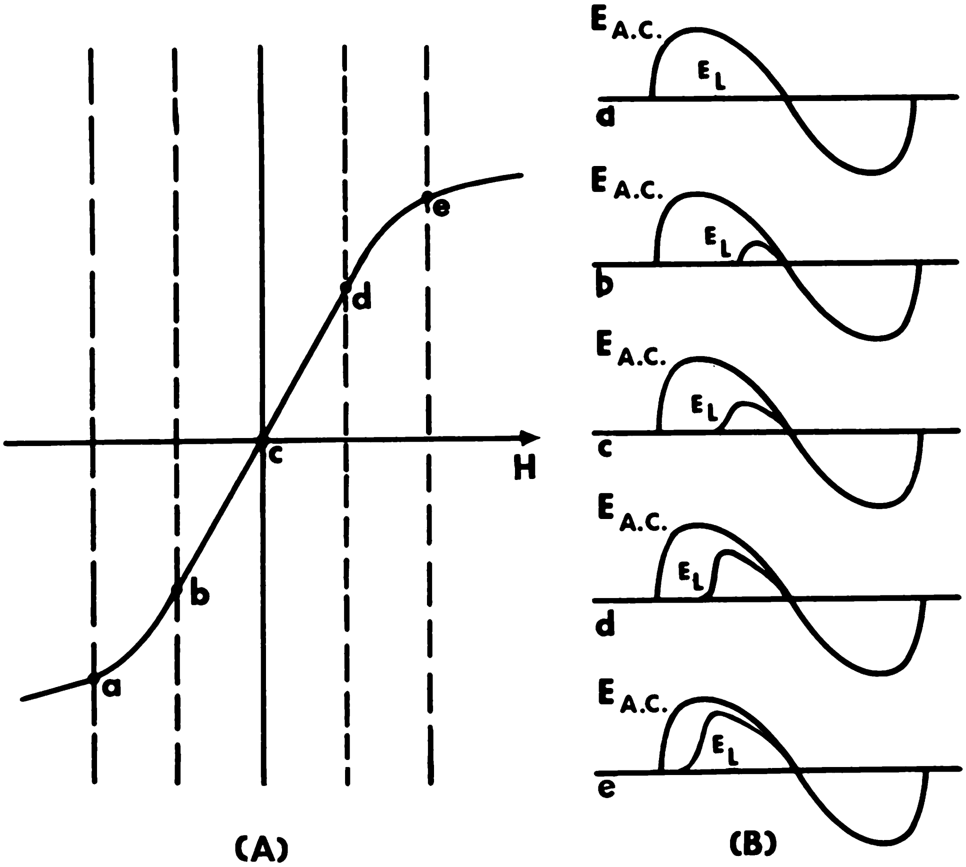


Figure 9-7.—Operation of a self-saturating magnetic amplifier.

increasing amount of control action. The operation in each case is basically the same as for figure 9-8(B).

It may be seen that the action described in the analysis mentioned above is similar to that of a thyratron. The control signal sets the point of amplitude at which the source voltage causes saturation of the core and reduces the impedance in series with the load winding to a very low value. In the thyratron, the control signal on the grid sets the point of amplitude at which the source voltage causes the tube to ionize, which results in a decreased impedance. The term firing, as it relates to the thyratron, is frequently used in connection with magnetic amplifiers interchangeably with the term saturation.

Using Bias for Flux Reset

When the core material possesses hysteresis properties that produce a rectangular-shaped B-H curve, it may be necessary to bias the core in order to retain control. This is accomplished by allowing a bias current to either flow through the control winding or through a separate bias winding. This bias current provides a means of resetting the flux to the initial operating point during the control period. Thus, no control current is necessary to reset the flux. Figure 9-9 shows a separate bias winding wound on the center leg of a three-legged core.

The core is usually biased so that with zero control current the load winding flux saturates the core midway in the operation cycle. This bias setting enables the control current to either advance or delay the point of saturation. In other words, if the polarity of the control current is such that the flux produced by it adds to the bias flux, the point of saturation will be delayed. (Control and bias flux are in opposition to load winding flux.) A control current of opposite

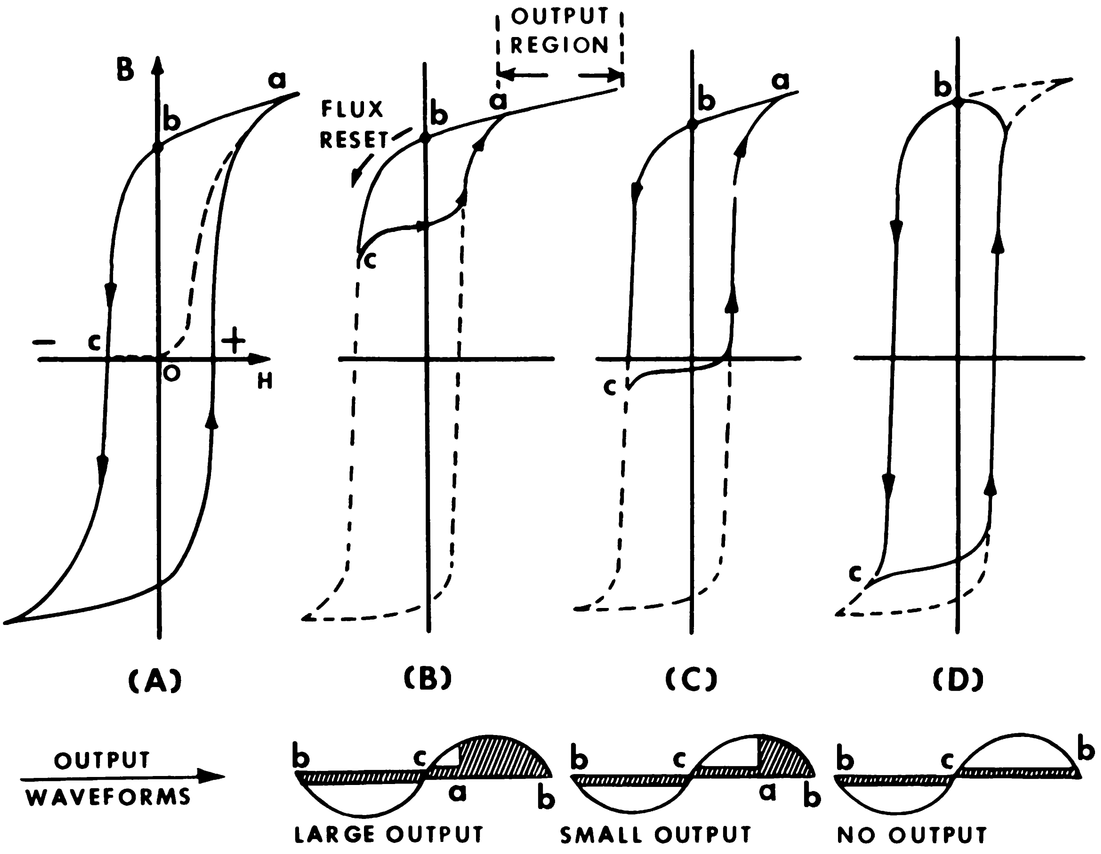


Figure 9-8.—Operation of a magnetic amplifier showing effects of hysteresis.

polarity will produce a flux that opposes the bias flux and this will advance the point of saturation.

The bias may be either alternating or direct current. In most cases the polarity of d-c bias is such that it opposes the load current flux. The magnitude of the bias might be such that it would reset the flux to a point between a and c of figure 9-2. There are some applications where the opposite is true; in these applications the purpose of the bias is to provide an initial d-c saturation in the core in order to obtain greater amplification of weak signals.

Full-wave Rectifier

The magnetic amplifier that has already been discussed produces a pulsating or half-wave output. In most applications of magnetic amplifiers, full-wave operation is more desirable for it is more efficient since the load is energized during both halves of the a-c cycle. Full-wave operation may be obtained by using a pair of simple half-wave magnetic amplifiers operating in parallel. A typical circuit arrangement is shown in (A) of figure 9-10.

The load current is controlled by means of two control windings connected in series. Each amplifier unit contains a rectifier so that load current flows alternately in the two amplifiers. As one conducts, the core of the series coil in the other is being set by the action of the control current. And with each amplifier conducting during approximately one-half of each cycle of load current, the output variations are full-wave in nature.

Output waveforms for two different control currents are shown in (C) and (D) of figure 9-10. The waveform in (C) is produced when the control current biases the core near the point of saturation. In this condition, saturation of the magnetic cores of the amplifiers is reached early in each half-cycle, and the resulting output

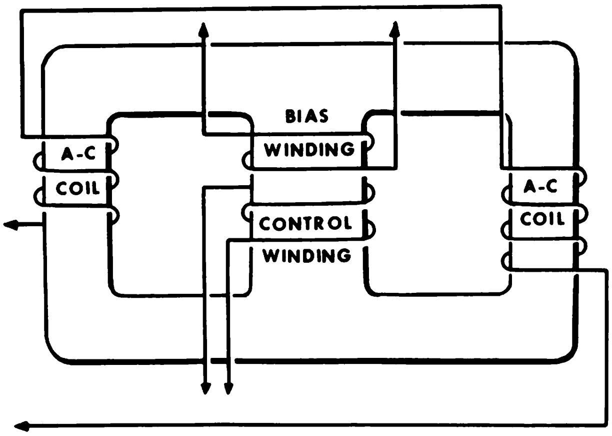


Figure 9-9.—Bias winding.

current variations are almost sinusoidal in shape.

When the current in the control winding biases the core in such a way as to produce the waveform of figure 9-10(D), the average value of load current is considerably less than when the control current biased the core to near saturation. Thus, as in the half-wave circuit, the output power developed in the load can be varied by controlling the load current. The output that is developed is an alternating current and is in phase with the source voltage. Figure 9-10(B) shows a magnetic amplifier that functions similar to the one shown in (A). The major difference is that the two cores shown in (A) have been combined to form a three-legged core.

CROSSOVER WINDINGS

In discussing the theory of operation of the full-wave magnetic amplifier circuits shown in figure 9-10, it was assumed that the rectifiers have zero forward resistance and infinite back resistance. In actual practice this assumption is not valid since rectifiers do not have infinite back resistance. It should be apparent that any back current flowing through the rectifiers shown in figure 9-10 (A) during their nonconducting half cycle, will produce a magnetic flux which will tend to drive the core out of saturation. During the conducting half-cycle a part of the load current would be absorbed in bringing the core back to the point of saturation, thus reducing the gain of the amplifier.

One method of counteracting this effect is by the addition of a crossover winding to the two magnetic amplifier cores. Figure 9-11 illustrates a magnetic amplifier utilizing full-wave rectification and crossover windings. It should be noted that this circuit is similar to the circuit shown in figure 9-10 (A) with the addition of the crossover windings.

The crossover winding consists of a few turns which produce a magnetic field in a direction opposite to that produced by the backward current through the load winding. Referring to figure 9-11, consider the action of the load and crossover windings on the two cores. Assume that during the first half cycle of the a-c supply voltage, rectifier 1 is conducting in the forward direction. The heavy current, flowing through rectifier 1 and the load winding on core 1, also flows through the crossover winding of core 2. During the same half-cycle a small backward current is flowing through rectifier 2, the load winding on core 2, and the crossover winding on core 1. This small backward current, flowing through the large number of turns in the load winding, produces a magnetic field that is canceled by the heavy current flowing through the small number of turns of the crossover winding on core 2. A similar cancellation is achieved on the second half-cycle of the a-c supply voltage by the other crossover winding.

Since the back resistance of the rectifiers will vary with temperature and applied voltage, some means must be provided to insure cancellation of the field resulting from the backward current at all times. A small constant resistance, R_S, is connected in parallel to the high, but variable, back resistance of the rectifiers. Each rectifier is shunted during its nonconducting half-cycle by the series combination of R_S and the conducting rectifier. The variations in the back resistance will now have no noticeable effect on the quantity of backward current through the load windings.

EXTERNAL FEEDBACK

It is possible to change some of the characteristics of a magnetic amplifier by the use of external feedback. (NOTE: The action of rectifiers in series with the load current discussed earlier in this chapter constitutes internal feedback.)

Feedback is the returning of a portion of the output of an amplifer stage to the input of that stage or a preceding

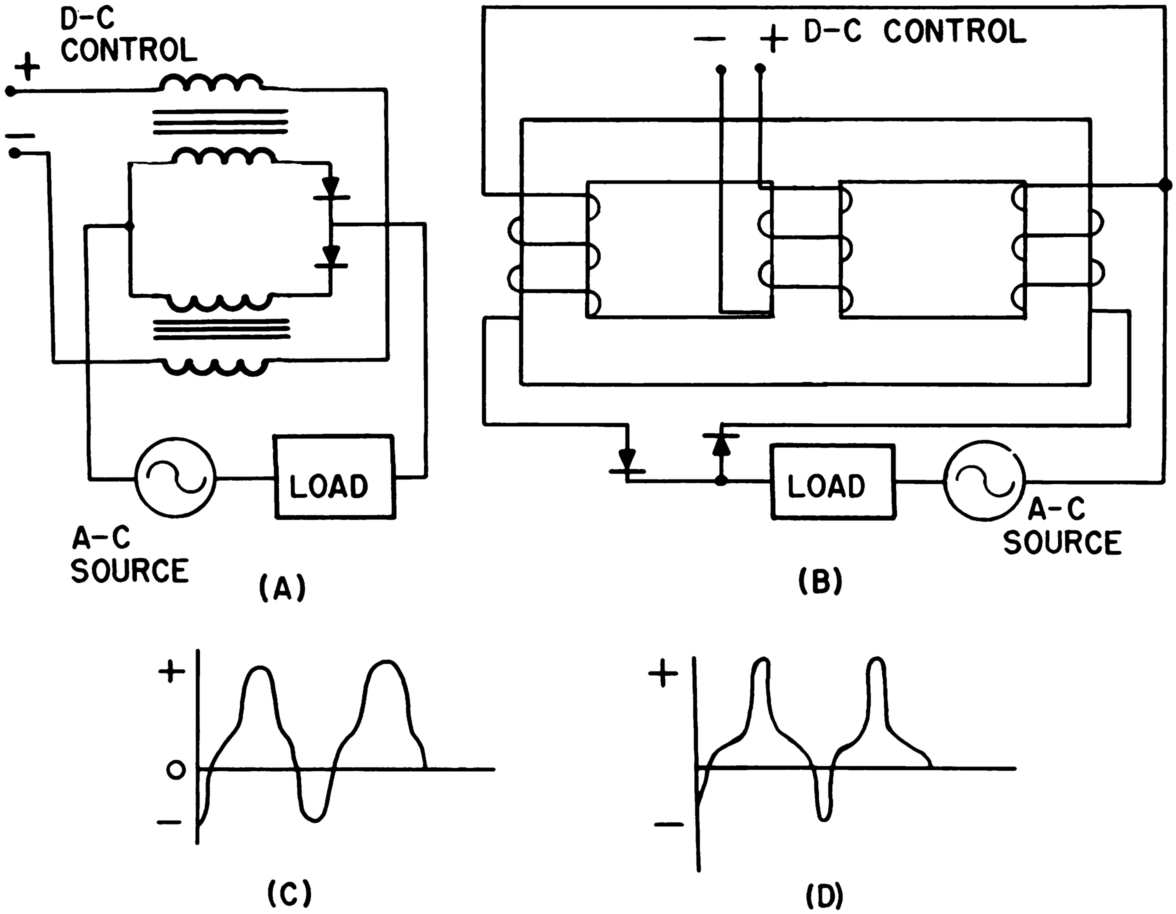


Figure 9-10.—Full-wave magnetic amplifier and output waveforms.

stage and may be either positive or negative lepending on the effect desired. It has the effect of adding to or subtracting from the flux lensity created by the control circuit current. Regenerative or positive feedback, which increases the control circuit flux density, makes he circuit more sensitive to changes in conrol current; thus, the power gain of a single stage may reach 40 to 50 db. However, this type of feedback has two disadvantages for it increases the time-lag characteristics of the amplifier, and may also cause instability. Degenerative or negative feedback reduces the gain of the amplifier by decreasing the flux density created by the control winding current; however, t increases the linearity of the magnetization curve and reduces the time-lag characteristics of the amplifier.

The curves in figure 9-12 illustrate the effect f both positive and negative feedback on load current as a function of input control current. It should be noted that the same amount of direct current is needed to saturate the core regardless of the amount of feedback provided. However, when using positive feedback, less input control current is required to saturate the core since the feedback current aids the control current toward this end. The gain characteristics of magnetic amplifiers with positive and negative feedback may be compared by studying the curves shown in figure 9-12. The following should be concluded:

1. Output current is the same when saturation is attained regardless of feedback.
2. Linearity and stability improve with degenerative (negative) feedback.
3. Gain improves with regenerative (positive) feedback.

A schematic diagram of two magnetic amplifier circuits utilizing external feedback is shown

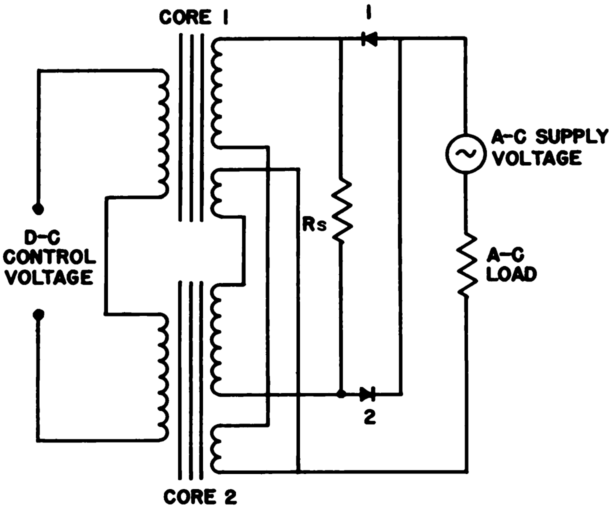


Figure 9-11.—Full-wave magnetic amplifier utilizing crossover windings.

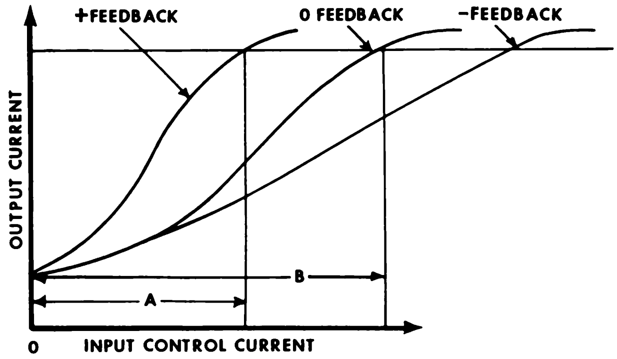


Figure 9-12.—Effects of external feedback.

in figure 9-13. Feedback is provided by an additional winding on the center leg of each core. The direct current flowing through the feedback winding creates a magnetic field which either aids or opposes the magnetic field created by the control current.

In (A) of figure 9-13 the a-c load current is rectified prior to being fed through the feedback winding. It should be noted that the feedback current consists of the total load current and it will always flow in the same direction regardless of the input signal. To change the feedback from regenerative to degenerative or vice versa, the feedback winding connections must be reversed.

Figure 9-13 (B) illustrates the use of external feedback in a magnetic amplifier supplying a d-c load. The amount of feedback is controlled in both circuits by the setting of the potentiometer paralleling the feedback winding.

Earlier in the discussion it was mentioned that the time of response of a magnetic amplifier was affected by feedback. Since this characteristic largely determines their application, we shall discuss this aspect further. The ordinary saturable reactor type, or saturable transformer, requires a certain time for a control action to take effect since the action is applied to an LR control circuit. The time of response is usually proportional to the time constant of the d-c input control circuit. The time constant for this inductive circuit may be determined by the equation

$$t = \frac{L}{R}$$

where

t is in seconds.
L is inductance in henrys of the control winding.
R is the resistance in ohms of the control winding.

This time constant may be reduced by increasing the control circuit resistance, but this causes a control power loss. Degenerative feedback can be employed to do the same if the reduced gain can be tolerated. A normal arrangement would be to apply degenerative feedback and add more stages in cascade. When stages are cascaded, a d-c output of the first stage is applied to the control winding of the next stage, and so on.

TOROIDAL CORES

In the discussion of magnetic amplifiers in this chapter, it has been assumed that the cores were constructed in such a manner as to meet the characteristics established by figure 9-5 and 9-8. For optimum performance, the laminations of a magnetic amplifier core should have the effective airgap as small as possible and be very thin to reduce eddy current effects to a minimum. The usual interleaving technique found in conventional transformer core construction is unsatisfactory for saturable reactors in magnetic amplifiers. The many small airgaps provided by butt joints of the standard E core distort

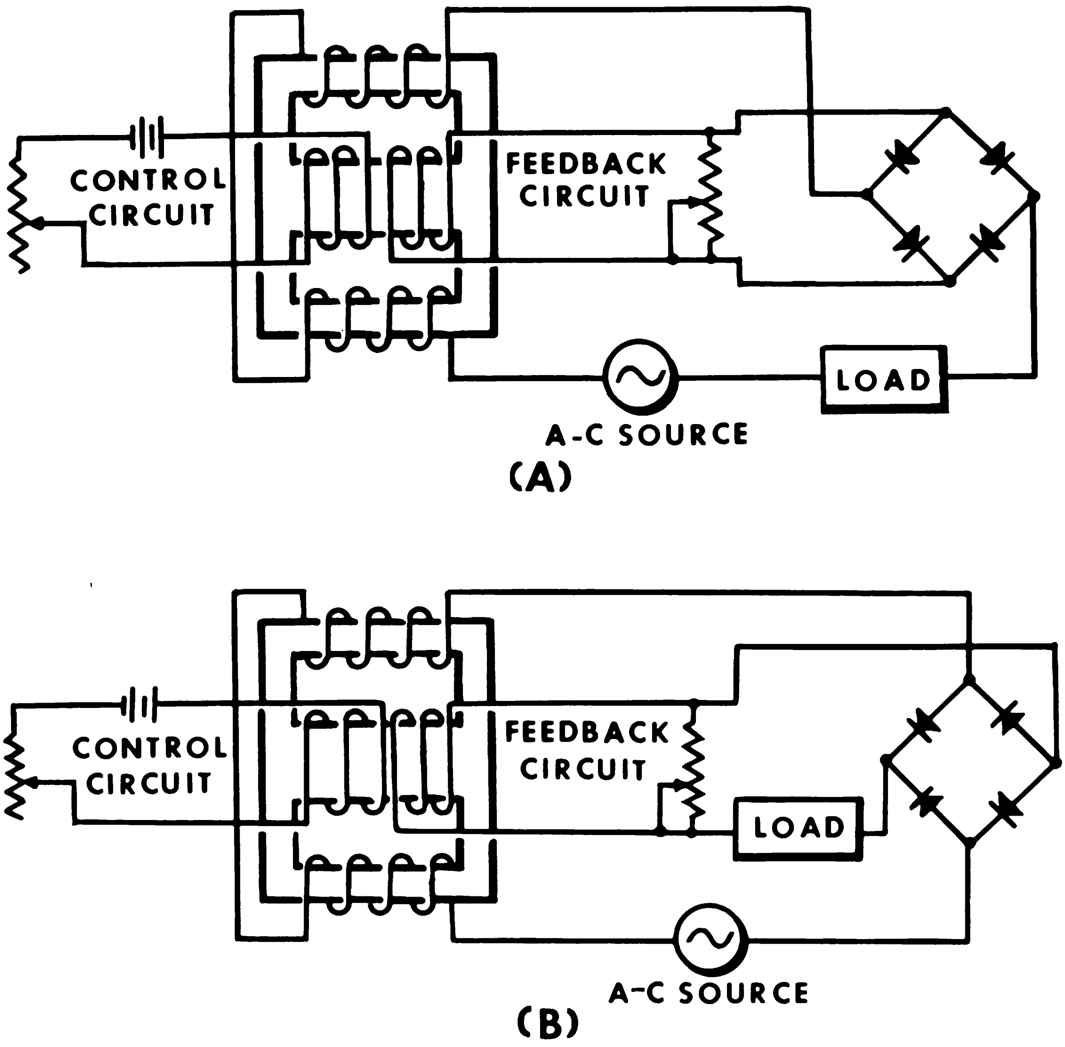


Figure 9-13.—Magnetic amplifiers using external feedback.

the magnetization curve, thus making it inadequate for peak performance necessary in most applications. Special design of the E core has improved its characteristics by increasing the overlap of the laminations for a greater portion of the magnetic path; however, its performance is somewhat below that desired.

A toroidal core is made by spirally winding a relatively narrow silicon steel tape forming a circular or rectangular core as required. The tape cores are mounted in loose fitting, insulated containers to provide support for the multilayer windings without placing mechanical strain on the cores.

Since toroidal cores have no center leg, two are required in most amplifiers. Figure 9-14 illustrates a basic magnetic amplifier utilizing two cores. The control windings are connected in series-aiding so that a common control current can saturate both cores. The a-c load windings are connected in series-opposing to minimize the alternating current induced in the control circuit.

The physical arrangement of the various windings on the cores will greatly affect the performance of the magnetic amplifier. They must be wound in such a way that leakage effects are reduced to a minimum and the circulation of alternating currents in the d-c control, bias, and feedback windings are minimized.

Typical magnetic amplifiers utilizing toroidal cores are discussed under Applications of

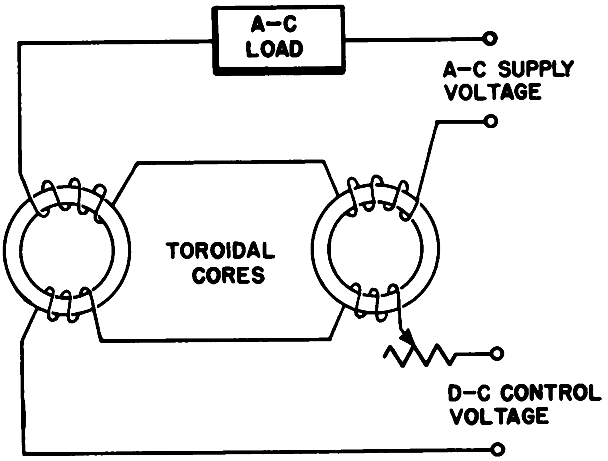


Figure 9-14.—Magnetic amplifier utilizing toroidal cores.

Magnetic Amplifiers. The use of bias, feedback, and crossover windings on toroidal cores are also discussed later in the chapter.

APPLICATIONS OF MAGNETIC AMPLIFIERS

The magnetic amplifier has found application in almost all circuits which use vacuum tubes and many which do not. They may be found in such circuits as audio amplifiers, voltage regulators, servoamplifiers, computer counting and dividing circuits, and many high frequency circuits. However, the Tradevman will be mainly concerned with their application in servosystems and in the various operations of computers.

ELECTRONIC POWER SUPPLY REGULATOR

Many electronic equipments contain voltage regulated power supplies. The accuracy of the voltage produced by these supplies is important insofar as proper operation and maximum life of the equipment are concerned. Present day electronic equipments contain many timing, waveshaping, and other critical circuits that require a constant d-c voltage source.

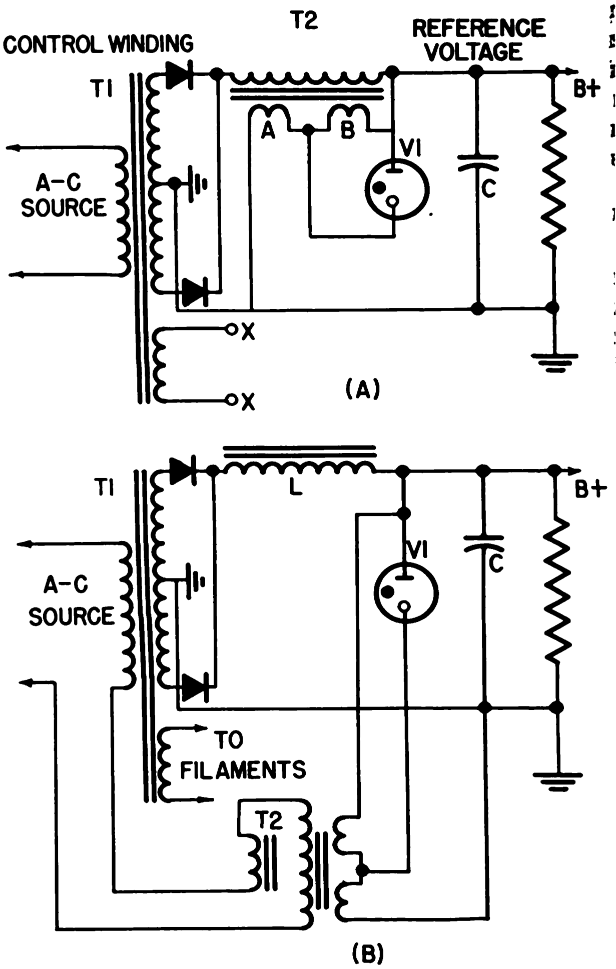


Figure 9-15.—Power supply using magnetic amplifier voltage regulator.

Figure 9-15 (A) shows a power supply which uses a magnetic amplifier to regulate the d-c output voltage. In this circuit the conventional filter choke has been replaced by a saturable reactor, T2. The voltage regulator (VR) tube (V1) produces a constant reference voltage across coil B and acts as a current amplifier for the control winding, A. Coils A and B control the saturation of T2, hence, the inductance of the load winding. This action effectively transfers filter capacitor C to the other side of the choke when the core is saturated. The end result is that the power supply alternates between a choke input and a capacitor input type of supply; thus a constant voltage output is produced.

Figure 9-15 (B) shows a variation of figure 9-15 (A) in which saturable reactor T2 is connected in series with the primary of power transformer T1. An advantage of this circui arrangement is that a regulated filament voltage is also produced.

The significance of constant filament voltage is appreciated when it is realized that the incidence of failure rises rapidly when the cathode or filament temperature exceeds optimum. This does not include transformer, choke, and resistance failures which can usually be traced to overloads occurring during these failures.

SERVOSYSTEMS

One of the most common uses of magnetic amplifiers is in connection with servosystems. Figure 9-16 illustrates the use of a magnetic amplifier as the output stage of a servoamplifier. The function of the servoamplifier is to amplify the servo error signal sufficiently to drive the servomotor. For a brief review of servosystems, refer to chapter 19 of Basic Electricity, NavPers 10086-A.

Before discussing the magnetic amplifier, let us briefly review the operation of an a-c servomotor. The output of the servoamplifier is connected to one of the motor windings (controlled winding) while the other winding (uncontrolled winding) is connected across the a-c source in series with a capacitor. The capacitor provides the required 90-degree phase shift necessary to cause motor rotation. The phase relationship of the current through the two windings determines the direction of rotation of the servomotor.

The input to the amplifier shown in figure 9-16 is a d-c error signal and is applied to the grid of

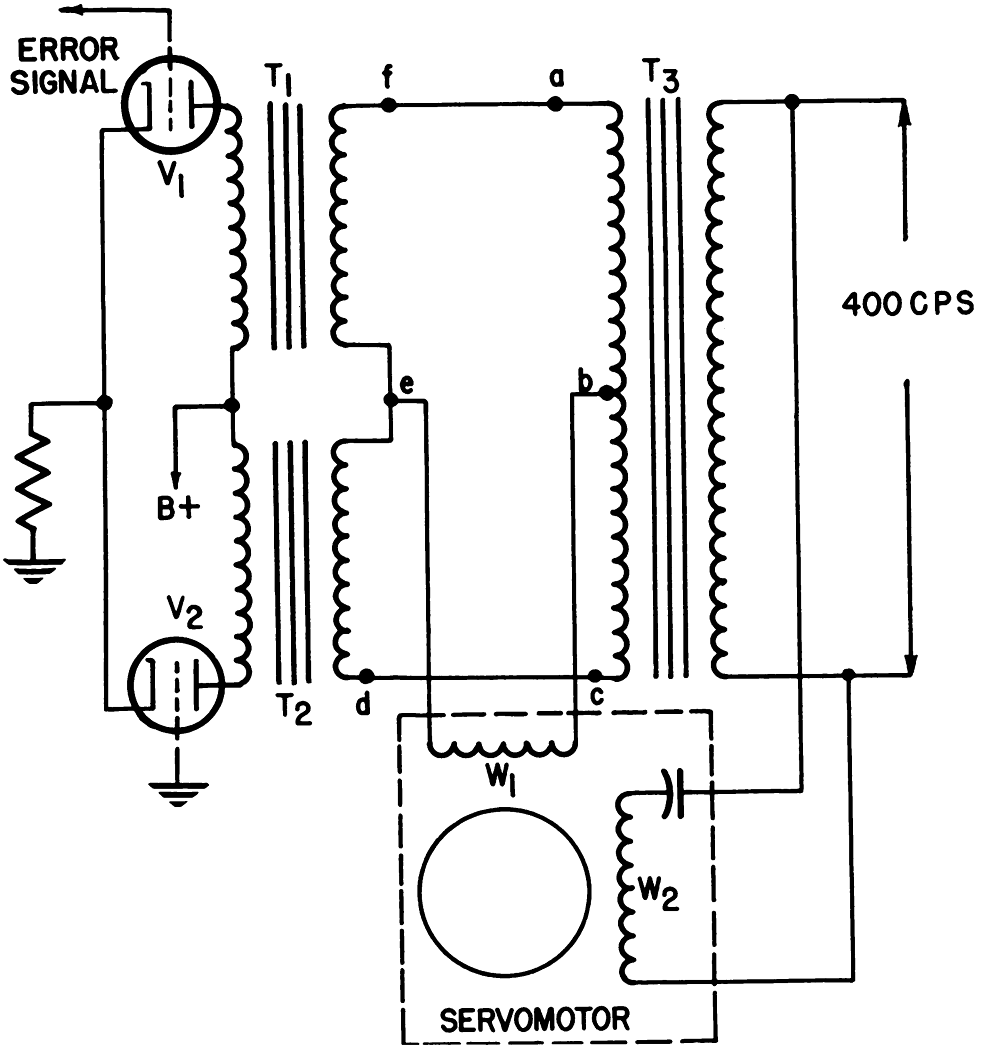


Figure 9-16.—Magnetic amplifier used as an output stage of a servoamplifier.

V1. Tubes V1 and V2 constitute a cathode-coupled paraphase amplifier working into two saturable reactors (magnetic amplifiers). The secondaries of the two saturable reactors and the two halves of the secondary of T3 form an a-c bridge circuit. The motor winding (W1) is connected across the bridge as shown. With a zero error signal applied, both tubes draw equal amounts of plate current partially saturating T1 and T2. Since the degree of saturation of the two saturable reactors is equal, the bridge circuit is still balanced and no current will flow in W1.

When a positive error signal is applied, V1 will conduct heavily while V2 will be near cutoff. At this time the secondary inductance of T1 will be practically zero. Motor winding W1 will be effectively connected across points a and b of T3 and supplied with an a-c source. Also at this time the secondary inductance of T2 will be very large (effectively an open circuit).

In a similar manner, when V2 conducts heavily, V1 will be near cutoff, the secondary inductance of T2 will be near zero, and the secondary inductance of T1 will approach maximum. Under these conditions, motor winding W1 is now effectively connected between points b and c of T3 and is supplied an a-c voltage that is 180° out of phase with the previous condition.

COMPUTER SYSTEMS

The Tradevman will find frequent application of magnetic amplifiers in computer systems. Figure 9-17 illustrates a typical magnetic amplifier. The a-c power source and the load are in series with the 50-volt and output leads, with their common connection grounded. The amplifier has shunted rectifiers, crossover windings, and produces an a-c output. It has three input windings: a control winding which receives the actual input signal, a bias winding which is connected through a resistor to a constant d-c source, and a third winding which may be used as a second control winding or as a feedback winding.

The two halves of the output winding are connected in parallel. Each branch of this winding is connected to the a-c source through a diode rectifier which permits current to flow through the two branches of alternate half cycles of the input. The two branches are connected so that current flow around the two magentic cores is always in the same direction. Thus, the effect of pulsating, direct-current flow around the magnetic cores is obtained.

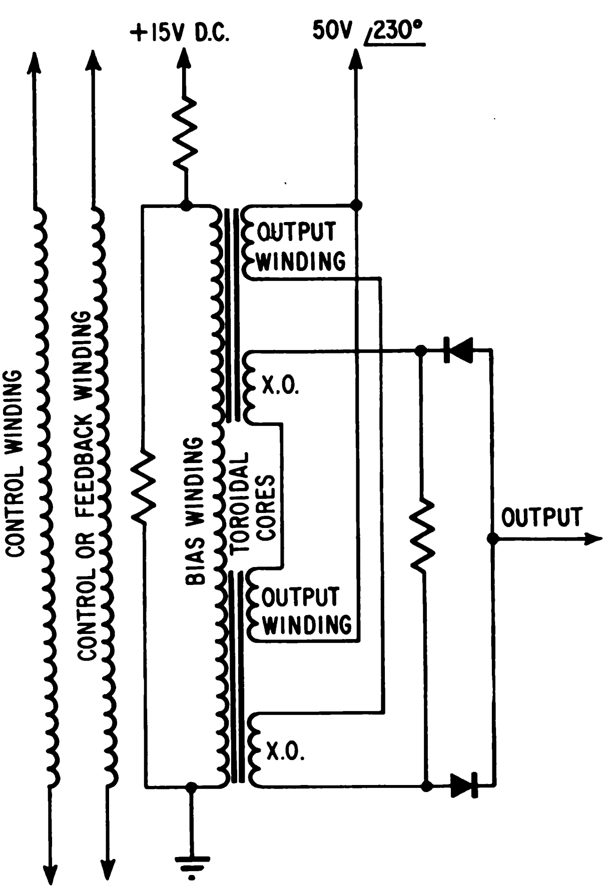


Figure 9-17.—Typical magnetic amplifier circuit.

The pulsating current passing through the output winding causes a varying magnetic field to form, with flux lines passing through and around the magnetic cores. The variation of the magnetic field induces a back emf that opposes current flow within the windings. Since the magnetic cores will support only so many lines of flux, the variation of the magnetic field may be decreased by passing a direct current through the control winding and partially saturating the magnetic cores. This decreased the inductive reactance of the output winding and permits more current to flow.

The crossover winding compensates for back current flow through the diodes. It can be seen in the figure that flux from a back current flow through the large segment of the output winding on either core is opposed by flux from a forward current flow through the small crossover winding on the same core. The number of turns of he crossover winding has been calcuated to compensate for back current low.

In most applications in computers, the feedack winding is connected to the output from the mplifier. This provides positive feedback which ompensates for some of the internal losses of he amplifier and increases the gain. The bias vinding increases the operating range of the amlifier and provides better control.

Frequently it is required that the output from a magnetic amplifier be d.c. rather than a.c. This can be accomplished simply by connecting the output of an a-c magnetic amplifier to a bridge rectifier, as shown in figure 9-18. In other cases, a magnetic amplifier is used which supplies a d-c voltage directly, as shown in figure 9-19. The fact that the output is d.c. can be verified by tracing current through the circuit for alternate half-cycle conditions.

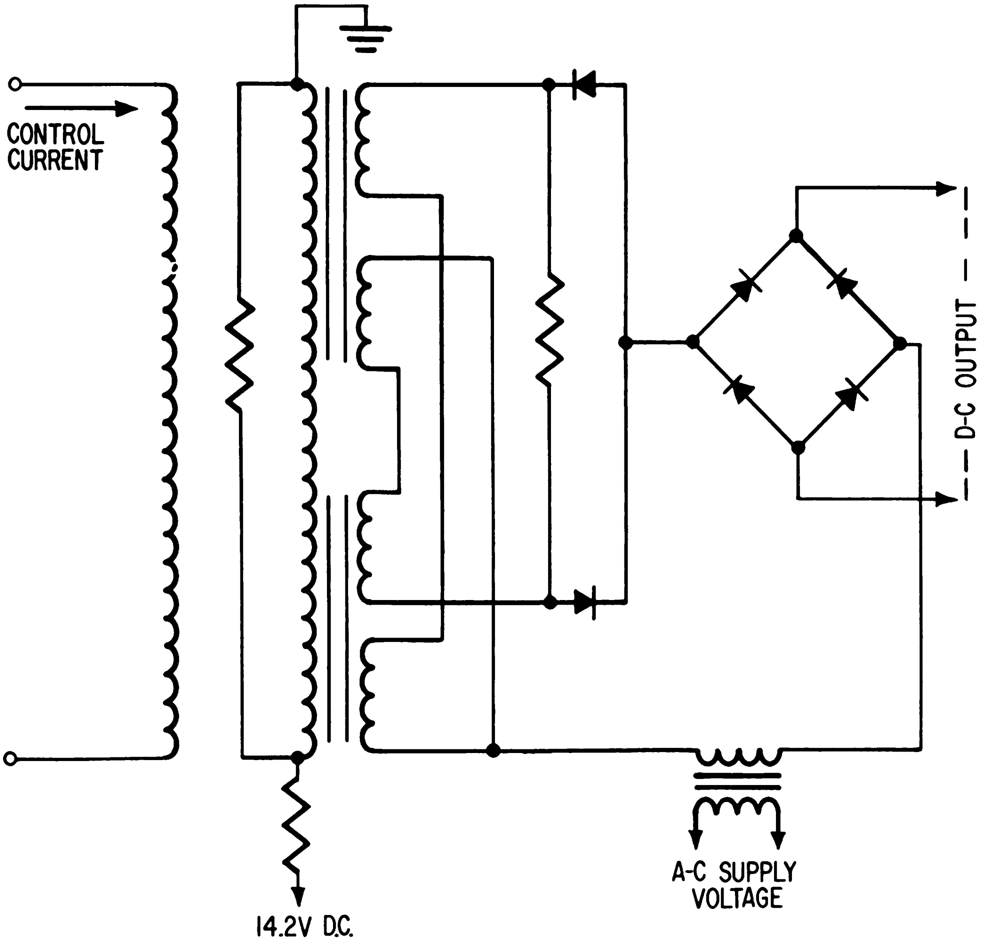


Figure 9-18.—Magnetic amplifier with bridge circuit.

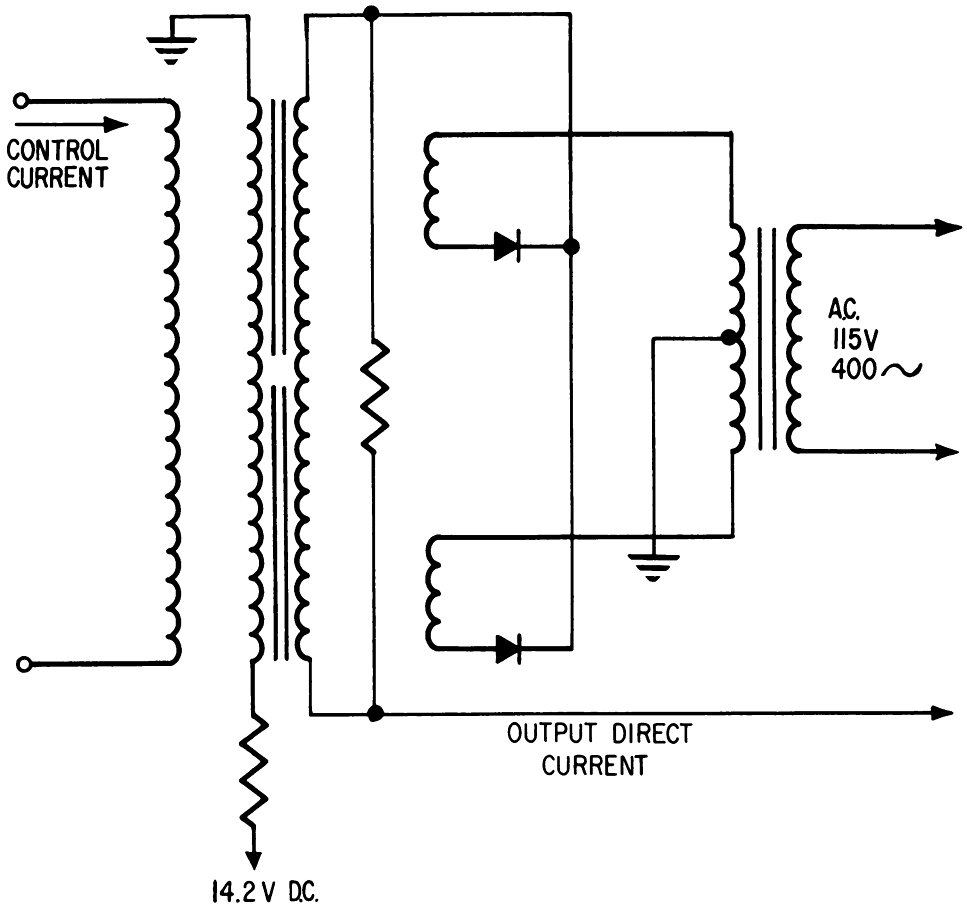


Figure 9-19.—Magnetic amplifier with d-c output.

CHAPTER 10

COMPUTERS

GENERAL PRINCIPLES OF COMPUTERS

Computers can add, subtract, multiply, and divide, or do calculus problems at speeds far beyond the capacity of the human brain. They produce correct answers in numerical form for use by statisticians, or in physical form for the control of machinery, military equipment such as gun directors, and synthetic training devices such as operational trainers.

Computers are often called mechanical brains because many of them operate on principles similar to those of the human brain. Unlike the human brain, however, properly operated and maintained computers have no unaccountable inconsistencies. They behave in a fixed pattern; and any man who understands this pattern can control and repair the machines. Computers operate according to basic mathematical rules, and contain only such simple elements as vacuum tubes, capacitors, variable resistors, motors, gears, relays, and synchros. All the operator or repairman needs is a sound knowledge of computer principles and operation, plus the ability to understand the function and capabilities of the machines he may be called upon to operate and repair.

All computers take input information, give meaning to it in a prescribed manner, and produce information. On a slide rule, for example, a strip is moved to indicate one input. The operator scans the strip to locate the second input, opposite which the output is indicated. Because the strip is graduated according to the logarithms of numbers, the output is the result of multiplication. The sum of the logarithms of the two inputs is equal to the logarithm of their product. If a problem requires a series of calculations, the operator merely transfers the answers from one step of the problem to the next, repeating the process as often as necessary.

Modern computers carry out all steps automatically once the operator has provided the input information. These inputs are measurable quantities which represent simple numbers or physical units such as temperature, speed, or pounds. Computing elements give purpose to the information by operating according to mathematical laws to perform the processes of adding, multiplying, integrating, etc. Outputs are numerical or physical quantities corresponding to the inputs and the mathematical operation performed.

COMPUTER TYPES

In their present stage of development, computers operate on one of two basic principles and, as a result, can be classified into two major systems: digital and analog. (NOTE: Basic Electronics, NavPers 10087-A, contains a discussion of both analog and digital principles. You should be familiar with the contents of this course before studying the material that follows.) Although this chapter is concerned primarily with analog computer principles and chapter 11 with digital computer principles, a brief comparison of the two systems follows.

In the typical digital computer, quantities are handled by counters which register increases or decreases in discrete (separate) steps. All mathematical processes are reduced to a series of additions or subtractions. For example, in the digital method of operation, 2 x 3 is handled as 2 + 2 + 2. In all cases, the sequences of the additions (or subtractions) are controlled so that they conform to the statement of an equation to be solved or to the necessary steps of an arithmetical computation to be carried out.

When digital computers are employed, complicated mathematical operations must be reduced to arithmetical operations before the problems can be solved. The digits representing the input information are fed into the computer and stored or "memorized" by means of relays, electronic tubes, or magnetic tape. The digits are then added or subtracted according to instructions provided by a punched program tape which is fed into the machine. Outputs representing the results of the computations are recorded on graphs, on punched cards, or in some cases, converted into typewritten answers.

Analog computers, with which this chapter is concerned, differ in several fundamental ways from digital machines. These differences include the manner in which the inputs are presented, the number of basic operations involved, and in the degree of accuracy of the computations.

In typical analog computers, the input data are represented by physical quantities, such as voltages, shaft rotations, or mechanical displacements. Unlike digital inputs, these quantities are continuously variable rather than varying in steps. Operating in response to the inputs, the analog computer provides a continuous solution which is correct at every instant, whereas the digital system must go through a certain sequence of steps before arriving at an answer.

Analog components perform a number of different kinds of operations including addition, subtraction, multiplication, integration, and differentiation, as well as other basic mathematical processes. The components are interconnected and vary in complexity with the number of processes for which the computer is designed.

In general, analog computers are not as accurate as comparable digital machines since analog accuracy is limited by the accuracy with which physical quantities can be measured. If accuracy in the order of 0.1 to 5 percent is satisfactory, analog equipment will give adequate performance with the advantage of relatively low cost. Operational trainers are examples of devices which employ analog computer principles; another familiar example is the simple slide rule, which is widely used by engineers and technicians.

Of major importance are the elements which are included in automatic analog computing systems. In general, these elements are of the types given in the following list:

1. Mechanical, in which mathematical processes are carried out by devices such as differentials, cams, gears, slides, and various kinds of linkages.
2. Electromechanical, in which the required processes are performed by combinations of electrical signals and mechanical motions; for example, synchros, potentiometers, and motors.
3. Electronic, in which mathematical processes are performed by using electrical voltages only; for example, amplifiers. Servomechanisms are usually employed in combination with electronic elements to supply any mechanical output required.

Training devices and simulators, like most single-purpose analog computers used in military equipment, fall into the electromechanical class. Inputs such as yards, degrees, or knots are converted to a proportional mechanical motion or to electrical currents and voltages. These analog units are combined and converted in various manners to satisfy the equation of the problem, and are reconverted into useful answers.

Servomechanisms are used extensively in performing computer operations for several reasons. They are remote control devices—an input can be applied at one point and the output produced at some other unit. They also readily convert electrical signals to mechanical motions and vice versa. This is important in analog computers, because it means that analogies may be set in as either voltages or shaft rotations.

COMPONENTS OF ANALOG COMPUTERS

The means of performing mathematical operations such as summation, multiplication, division, differentiation, integration, vector resolution, coordinate conversion, and special function generation are included in most analog computers and are explained later in this chapter. Multipurpose commercial analog computers usually have specific functional units assigned to perform certain mathematical operations. For example, they may contain a bank of ten summation amplifiers and ten integration amplifiers. Complete solutions are obtained by interconnecting the appropriate units by means of cables.

Single-purpose analog computers, such as flight trainers, generally contain apparatus grouped in sections according to equations to be solved rather than in banks of similar circuits. Thus, one chassis might be concerned with angle of attack, another with heading, and a third with altitude. Interconnections between the various chassis are used to cause the trainer as a whole to react realistically to the flight environment and the control movements made by the pilot. Analog computers are usually comprised of the following functional units:

1. Linear computing elements. These perform summation (addition and subtraction), phase inversion, multiplication, and division, and are often completely electronic.
2. Nonlinear computing elements. These perform mathematical operations involving one variable as a nonlinear function of another. Servomechanisms are used to carry out such processes as logarithmic solutions and special function generation.
3. Scale factor resistors. These elements make analog units proportional to equation units, and also set in coefficients of equation terms.
4. Power supplies. These furnish voltages needed by the electronic components.

Single-purpose analog computers produce answers on visual-display indicators and simulate natural reaction forces; for example, readings on turn-and-bank indicators and reactions to the aircraft's control stick.

A TYPICAL ANALOG COMPUTER

This chapter describes a few of the many methods of automatically carrying out computations which are involved in simulating real situations. However, before attempting to understand computer operation, the reader must know the answers to such questions as:

1. What is its purpose?
2. What equations does it solve?
3. In what form are the solutions presented?

What computational techniques are used and how they are applied can then be determined.

Figure 10-1 illustrates the relationship between an actual physical situation and its electromechanical analog. The physical situation is that of an aircraft in flight. The electromechanical analog in this instance is a group of servomechanism computers which solve the equations of flight. In the simulator, motions of the pilot which ordinarily control the aircraft are used to control variables in the equations of flight. The solutions to these equations are in the form of instrument panel indications and stick and rudder reactions to which the pilot responds. For example, if the aircraft is flying straight and level and the pilot wishes to turn to the right, he moves the stick to the right. The movement of the stick is transmitted electrically to computers where it affects the flight equations related to lateral performance. As a result, the turn needle is deflected, the pilot feels the controls respond to the forces generated by the turn, and alters his movement of the controls accordingly. Analog computers solve the equations for:

1. Rate of turn.
2. True airspeed.
3. Groundspeed.
4. Track.

Since one of the purposes of the synthetic flight trainer is to solve for track and groundspeed, these solutions are fed to a plotter which makes a record of the flight. The simplified functional diagram (fig. 10-1) shows the inputs of lift, thrust, drag, centrifugal force, and gravity which are combined to give an output of groundspeed.

COMPUTER SERVOMECHANISMS

Servomechanisms play an important part in the functioning of an electromechanical analog computer. In such a computer, a servomechanism output in the form of a voltage or shaft position will result from input signals introduced at some remote location. The output reflects the input accurately, because feedback makes its result independent of such factors as load change and line voltage variation. Servomechanisms are power amplifying devices as well as remote control systems. They are used extensively in computers to convert mechanical variables to electrical variables, or vice versa.

The principle on which servomechanisms operate is described in TD 3 & 2, NavPers 10376-A and Basic Electricity, NavPers 10086-A. The two basic types of servomechanisms are position servos, which produce an output position corrrsponding to an input signal; and velocity servos, which produce an output speed proportional to an input signal.

Power for servos may be electromechanical, pneumatic, or hydraulic. Electromechanical servos are almost universally employed in analog computers because of their characteristics of flexibility, accuracy, and speed. In cases where given loads require considerable power, pneumatic or hydraulic systems may be used.

ELEMENTS OF SERVOMECHANISM

The basic elements of a typical position servosystem are the error detector, controller,

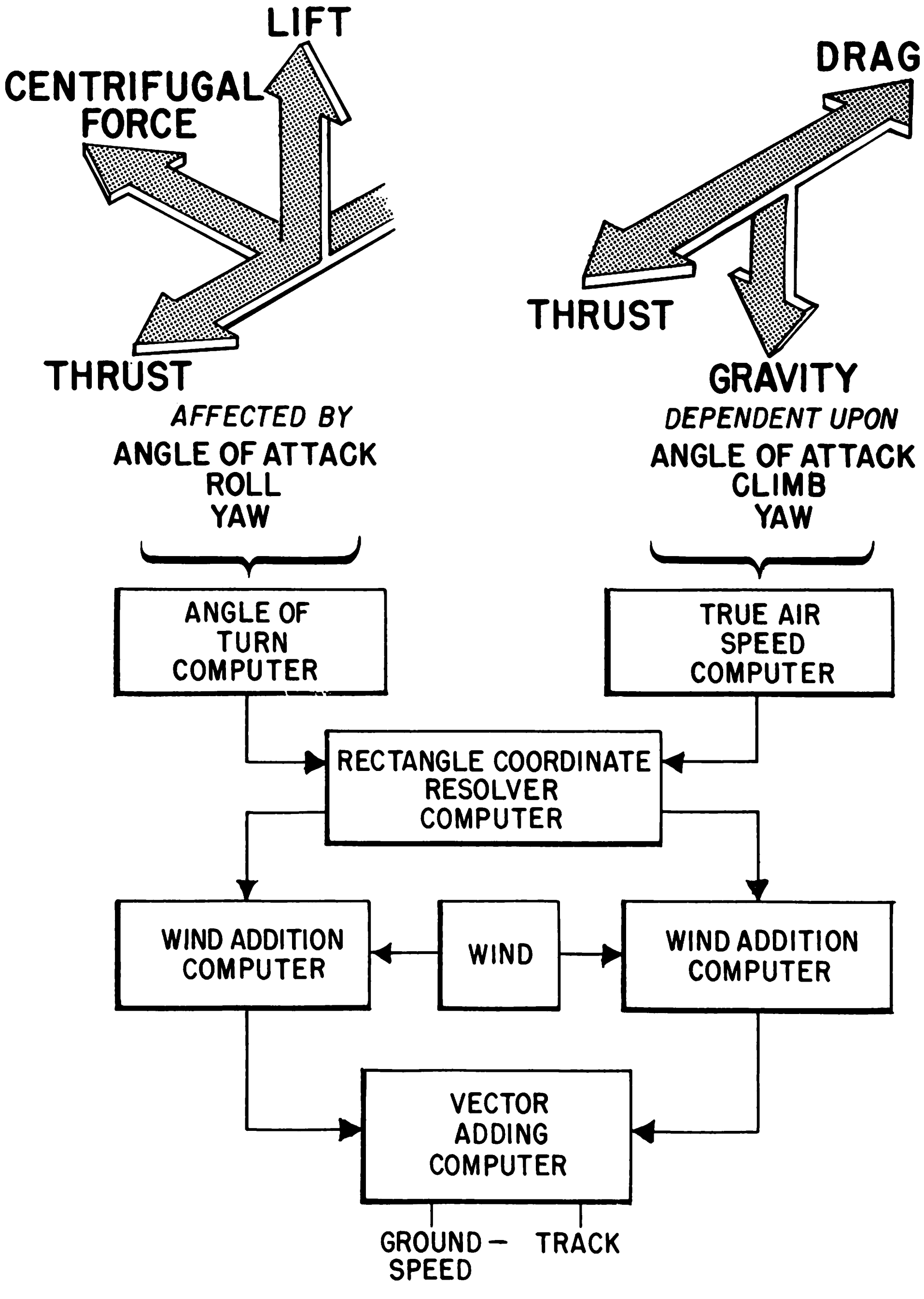


Figure 10-1.—Functional diagram of a typical analog computer.

motor, and followup loop (sometimes called feedback loop) (See fig. 10-2.) Input and followup signals are subtracted in the error detector, and transducers are used to insure that all the signals are in compatible forms. Any error signal is amplified by the controller and produces torque in the motor. The motor output drives the load.

Input

The input may be in any one of many varied forms—motion, pressure, temperature, etc.; but the command signal to the controller must be in a form suited to the capabilities of the controller. In computer servomechanisms the input information is usually in the form of a voltage, shaft position, or velocity. The error signal to an electronic controller must be a voltage. The followup may be a voltage or a mechanical quantity. Units such as potentiometers, synchros, and strain gages are used to convert data from one form to another, and are called transducers. In some instances a second transducer may be needed in the followup loop to convert the output into the same form as the command signal, so that subtraction may be made to form the error signal.

Transducers

Where the input or output has limited motion, potentiometers are generally used. (See fig. 10-3.) In single-turn potentiometers the shaft motion may be 350° or less. They may be used with either a.c. or d.c. Potentiometers may also be used to generate nonlinear functions. Potentiometers are subject to limited resolution because there is a voltage drop between the adjacent turns of the wire. There is also wear of wiper and resistance wire.

Synchro transmitters can also be used to transform shaft motion into electrical signals with unlimited resolution and rotation. They may be employed in two-speed combinations to develop extremely high angular accuracy. Differentials and control transformers, which are modifications of synchros, are widely used. The servomotor drives the control transformer rotor until the rotor voltage is canceled, at which time its position corresponds to the position of the rotor of a remote synchro transmitter. Therefore, the servo output follows the input motion of the transmitter. In this case, the control transformer acts as an error detector as well as a transducer. (See fig. 10-4.)

Error Detectors

The error detector or differential is a subtracting device such as a parallel resistor summation network (fig. 10-3), or a control transformer, which produces an error signal voltage equal to the difference between the command and the followup signals: $e = V_{in} - V$

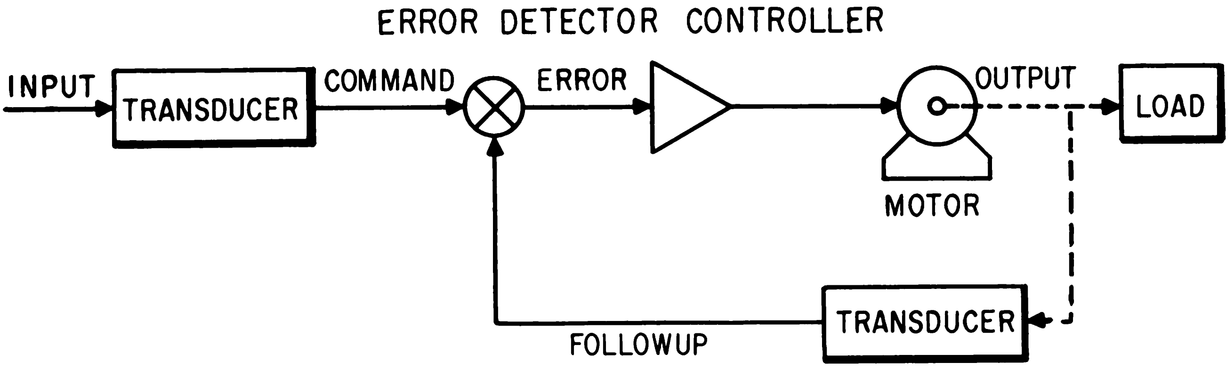


Figure 10-2.—Block diagram of basic servomechanism elements.

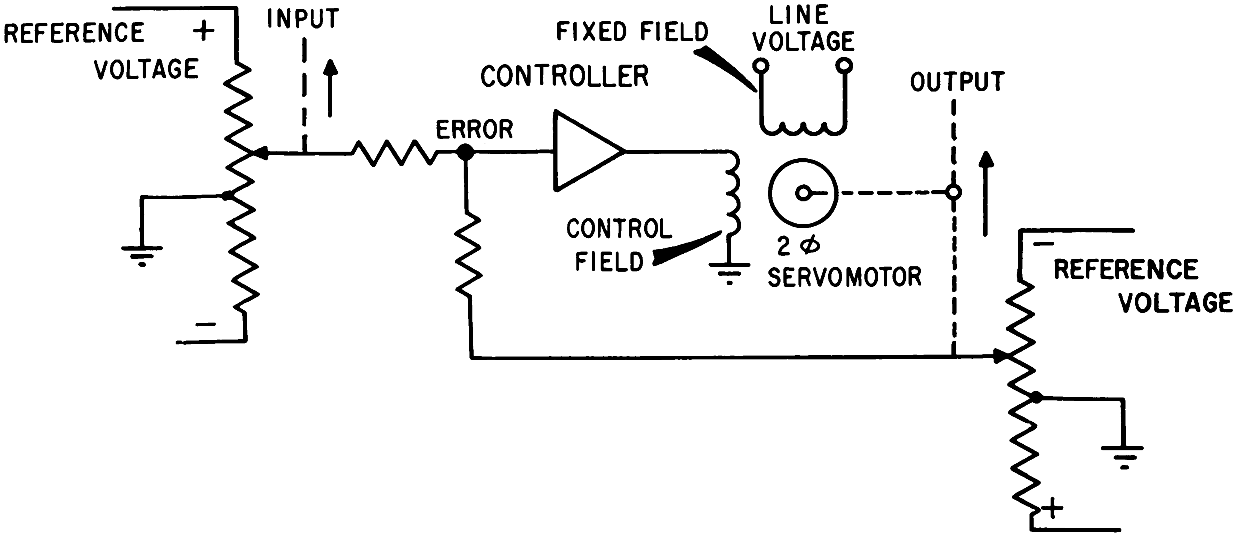


Figure 10-3.—Typical servosystem utilizing potentiometers as input and followup units.

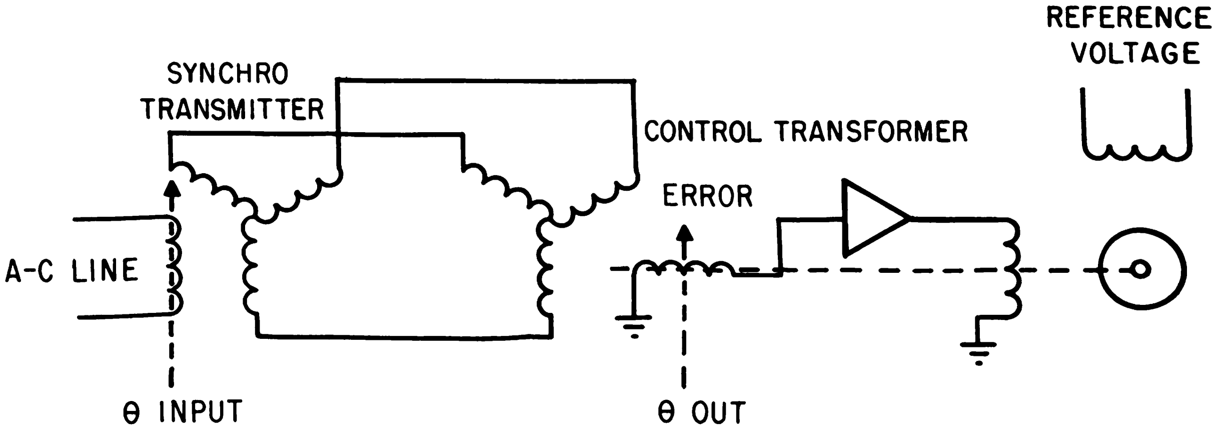


Figure 10-4.—Control transformer in a servomechanism.

(followup). As the error approaches zero, the value of V_{in} approaches that of V_{out}. However, until the error is nulled, the amplified error signal is sufficient to develop a torque to run the motor.

Controller

The servocontroller amplifies the error signal to produce sufficient power to drive the motor. The power output is adequate to meet maximum load requirements of the motor. The gain of the controller is high enough so that small error voltages will affect the output to give good positional (static) accuracy. Too high a gain will produce instability.

The design of the amplifier circuit of the controller depends upon whether the error is d.c. or a.c., and upon what type of motor is used. Usually a-c amplifiers are used because of their greater simplicity and stability. High gain is easily achieved, and there is no d-c drift problem.

Modulators and phase detectors are necessary to convert signals from d.c. to a.c. and back to d.c.

When d.c. is converted to a.c., both polarity and magnitude of the d-c signal must be contained in the resulting a.c. Modulator circuits that convert d.c. to a.c. contain switching type elements such as diodes, crystal or metallic rectifiers, clamping circuits, and mechanical contactors. The switching elements are operated at a carrier frequency and the resulting a.c. is a series of pulsating voltages in which amplitudes equal the d-c error voltage.

In d-c analog computers a phase detector is required to convert an alternating error voltage to a direct voltage. The amplitude and polarity of the d-c voltage must correspond to the polarity of the error signal. A simple full-wave rectifier circuit produces a d-c voltage irrespective of the half-cycle polarity, but the phase detector switches to produce the proper polarity. Phase detectors operate on the principle of adding the error signal to, and subtracting it from, a reference voltage and then rectifying the resulting a.c.

When using a-c analog computers, a phase detector is employed when it is desired to compare an input voltage phase with a reference phase. This is normally done to switch the inputs feeding a certain servosystem.

Motors

An electric motor usually supplies the output. If the output should be translatory (straight-line motion) instead of rotary, solenoids or other devices are used. Servomotors have a linear torque/rpm characteristic over a great range of voltages so that the output speed is proportional to the error. For good acceleration characteristics, the ratio of motor torque to rotor inertia is high.

The 2-phase induction motor is the most widely used a-c servomotor. The reference-phase winding is excited by the fixed line voltage. The control-phase winding is excited by the error voltage from the controller, and is 90° (or 270°) out of phase with the reference voltage. The magnitude of the amplified error voltage determines the motor torque; and the phase angle, with respect to the reference line voltage, determines the direction of rotation.

The d-c servomotor most frequently employed is the shunt motor which is controlled by varying the armature current. Current is controlled by vacuum tubes or thyratrons in the controller. In some small motors the field is a permanent magnet.

Friction or magnetic fluid clutches located between continuously running motors and the load are sometimes used with servomotors and are actuated by the controller. Current to clutch coils can produce any desired amount of coupling so that the output motion follows the input with the required smoothness and accuracy. A detailed description of motors is contained in Basic Electricity, NavPers 10086-A.

Output

The output is the controlled quantity which is proportional to the input quantity. In a position servo, the output is the angular displacement of a shaft geared to the motor shaft. This mechanical output may position a potentiometer wiper or a synchro control transformer to produce an electrical output. In a velocity servo, the output is a shaft speed.

Load

The load includes all factors which the servomotor must overcome. These factors include gear train and bearing friction, inertia, and friction of any components driven by the motor. A typical position servo using a 2-phase motor and potentiometers as transducers is shown in figure 10-3.

STABILITY AND ACCURACY OF SERVOS

In position servo operation, a change in the input causes the output motor to drive the followup transducer in a direction determined by the polarity (or phase) of the error signal to cancel or null the input change. If the input signal is larger than the followup, the output moves in the direction to increase followup. When the error is reduced to zero, the controller output drops and does not drive the motor. However, inertia of moving parts causes the motor shaft to continue rotating even when no voltage is supplied to the motor. As the output goes beyond the position which would cancel the input, the followup voltage becomes larger than the input voltage and the error changes polarity. The motor is braked by the reverse signal. If the error voltage caused by followup again drives the motor beyond the null, the process repeats and the system oscillates or hunts. However, the error signals must develop a motor torque sufficient to overcome frictional loads; and if the overshoot is not significant, the error may not be large enough to drive the output further. The range of the error voltage variation which does not overcome frictional loads is called the dead zone. If friction loads are high or the servo gain low, the system may come to rest within the dead zone without hunting.

In most instances, some external damping factor must be added to reduce inertia effects. A servo is said to be underdamped if it overshoots the correct position and has no sustained oscillation. If the servo is overdamped, or loaded excessively for its gain, the null is reached without hunting, but dynamic accuracy suffers since the output does not respond instantaneously and is slow in reaching the null position. (The servo is said to have velocity and acceleration lag.) The servo is critically damped if the output follows the input without delay and does not overshoot the null when it is first reached.

To avoid hunting conditions, the servo must be damped, or some means of anticipating the null must be provided so that the motor can be braked before the desired output position is reached. The latter method is better in that gain and acceleration capabilities are not sacrificed.

A servo generator driven by the servo output produces a voltage proportional to rotor speed which may be used for damping. If this voltage is fed into the controller with a polarity opposite to the error voltage, it creates an apparent null advanced beyond the actual null. When the motor slows down, the generator voltage decreases and becomes zero when the motor stops.

Because the generator voltage is fed back, the error signal required to maintain a given servomotor velocity must be larger than would be necessary without stabilization. This type of stabilization therefore causes a large velocity lag error. Servo generator stabilization, however, has the advantage of being simple to adjust; it is relatively independent of backlash in the gear train; and it has no effect on the static gain of the controller.

A velocity servo produces a motor velocity corresponding to an input voltage. The total number of revolutions made by the motor shaft is the time integral of the input voltage. An ideal 2-phase induction servomotor would run at the same speed as the rotating flux regardless of the applied voltage if power loss and friction were zero. The torque necessary to overcome these losses is developed as the rotor slows down; but as loads also require torque, in practice, the actual speed is proportional to the torque developed, minus load torque. The motor speed, therefore, is a function of both applied voltage and load.

Velocity servos must compensate for speed changes due to varying loads. In many cases the velocity servo employs a servo generator to produce a feedback voltage which is proportional to the speed at which the generator is driven. The voltage from the controller to the motor is a function of the difference between the input quantity and the velocity of the output shaft. The tendency of the motor speed to decrease with load is overcome by the feedback signal produced by the servo generator. If the feedback signal is less than the input, the resulting error voltage will increase the motor speed until the increasing feedback cancels the input, thereby holding the motor speed proportional to the input. When a load torque is applied to the output shaft, its velocity decreases; but this, in turn, causes an error signal which produces more controller output to supply the torque demand. With a high controller gain, full motor torque can be developed with only a slight velocity error.

POWER SERVOS

The instrument servomechanisms employed in computers are seldom required to develop large power outputs, since in most cases they drive small loads such as low-mass gear trains, synchros, and potentiometers. On the other hand, the servomechanisms which drive radar antennas, direct antiaircraft guns, steer ships, and control guided missiles must produce large amounts of power. For these applications, pneumatic, hydraulic, and specialized electrical servos are used. The heavy equipment must be driven at varying speeds, it must be capable of positioning the load member in both the forward and reverse directions, and it is usually necessary that it be operated by remote control. The basic elements of power servomechanisms are identical in principle with corresponding elements of electromechanical instrument servos. In heavy-duty applications, however, the final stages, or servomotors, are characterized by large output-power capabilities; and in most cases, they require greater amounts of control power than instrument servos.

Figure 10-5 shows a pneumatic servo which is similar to the Servomechanism Demonstrator Device 3K41 discussed in TD 3 & 2, NavPers 10376-A. The operation of the system is governed by a regulator valve, which controls the flow of air under high pressure to the piston. The feedback data and the input command signals are applied in the form of shaft displacements, which are applied to a mechanical differential. The latter element combines the applied displacements and produces an error signal for controlling the action of the system. In pneumatic servos (such as those employed in some guided missiles), the exhaust can be released to the atmosphere after passing through the system only once.

A high-power servomotor operating on electrical principles is illustrated in figure 10-6. The servomotor proper consists of a combination of d-c generator, and d-c motor. The generator which is of special construction, is called an amplidyne. It is driven by a heavy-duty a-c motor and provides direct energy to the final d-c motor which controls the position of the final load member. The amplidyne gives a high output with less control power than the conventional d-c generator. It contains a short-circuit loop in the armature circuit in addition to the brushes from which the output current is taken. Very little control current is required to produce high current in the short circuit; as a result, this arrangement is equivalent to one stage of amplification. The large flux set up by the short-circuit current induces sufficient voltage to drive an equally large current through the external load, thereby providing effectively a second stage of amplification.

MATHEMATICAL OPERATIONS WITH COMPUTERS

A computer is generally capable of performing numerous types of mathematical operations. This includes the linear type such as addition and subtraction, and also nonlinear processes such as deriving powers and roots. This section of the chapter reviews the circuitry and mechanisms used in performing these operations. The theory of operation of each is also discussed.

It should be remembered that the major objective of the analog computer as used in training devices is the computation of variable factors, such as velocities, angles, and rates, and their interrelation to each other in the overall picture. In a typical process—squaring, for example—the computer may be dealing with a formula for the distance traveled by a falling body:

$$d = \frac{gt^2}{2} + V_0t$$

where the t factor (time) is squared. The computer might very well represent time as a

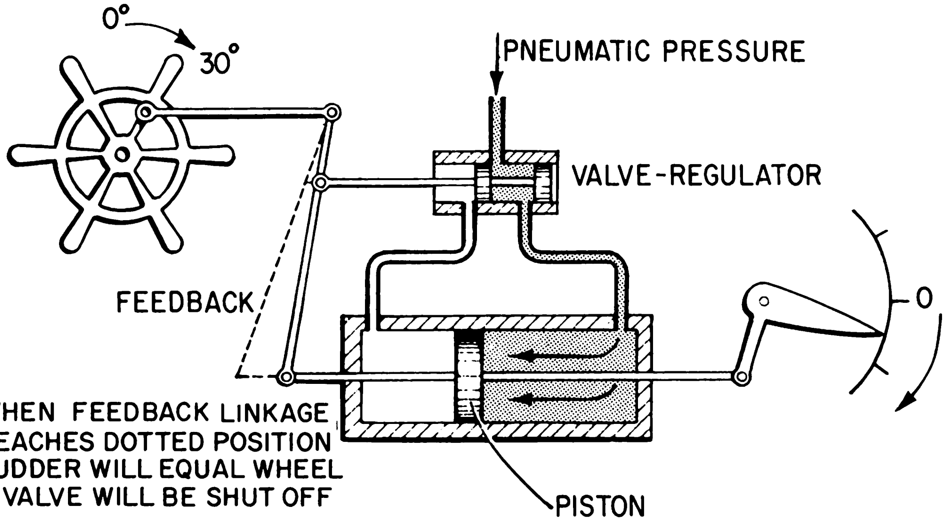

0°
30°
PNEUMATIC PRESSURE
VALVE-REGULATOR
FEEDBACK
0
WHEN FEEDBACK LINKAGE REACHES DOTTED POSITION RUDDER WILL EQUAL WHEEL & VALVE WILL BE SHUT OFF
PISTON

Figure 10-5.—Pneumatic servomechanism.

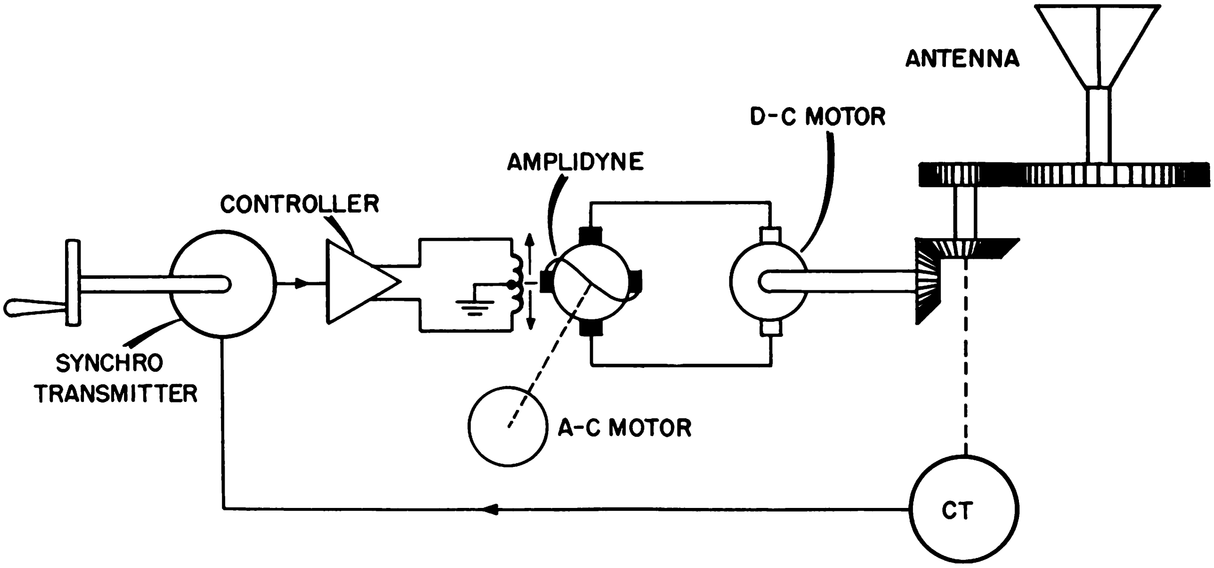


Figure 10-6.—Simplified diagram of an amplidyne servo.

voltage which, when processed through a squaring circuit, produces a result which is proportional to t^2. the proportional answer can be converted to a true answer through the use of a scale factor. In analog computers a scale factor is obtained by dividing analog units by physical units:

$$\text{scale factor} = \frac{\text{analog units}}{\text{physical units}}$$

For example, if it is desired to represent 10 feet by 1 volt, the 10-foot value is the physical quantity, the 1 volt is the analogous quantity, and the scale factor is thus 1/10. As a general rule, a true answer is obtained by dividing the actual output quantity by the scale factor.

SUMMATION

The process of summation can be accomplished with electronic, mechanical, or electromechanical means. Voltages may be added; motions may be added; or voltages and motions may be combined to produce an output proportional to the inputs. Figure 10-7 illustrates a simple electrical summation device—a series circuit. In this instance, the output voltage E_o is simply the result of the series addition of the input voltages E_1 and E_2. ($E_o = E_1 + E_2$.) In a circuit of this type, the input voltages are a.c., and the addition holds true if the phases of the voltages coincide. Of course, if voltages are 180° out of phase, subtraction rather than addition occurs and the output becomes the difference between E_1 and E_2. ($E_o = E_1 - E_2$.) The combination of voltages that are displaced by phase angles other than zero or 180° results in a phase shift and consequently an error in output. In series adding circuits, only one of the input voltages can be grounded. Any others must be isolated from ground. This type of circuit is used primarily when voltage sources are inductive units, such as synchros and resolvers.

A parallel resistance network can also be used to produce electrically the sum of several inputs. In the circuit shown in figure 10-8, the output voltage is not the actual sum of the voltages, but is proportional to that sum.

The operation of the summing network can be understood by means of the following analysis. If all three of the resistors are of the same value, the output is related to the two inputs as follows:

$$E_{output} = \frac{E_1 + E_2}{3}$$

This equation is derived by applying Kirchhoff's law for the two loop currents indicated in figure 10-8 in the following manner:

$$E_1 = E_2 + I_1R - I_2R + I_1R$$

$$E_2 = I_2R + I_2R - I_1R$$

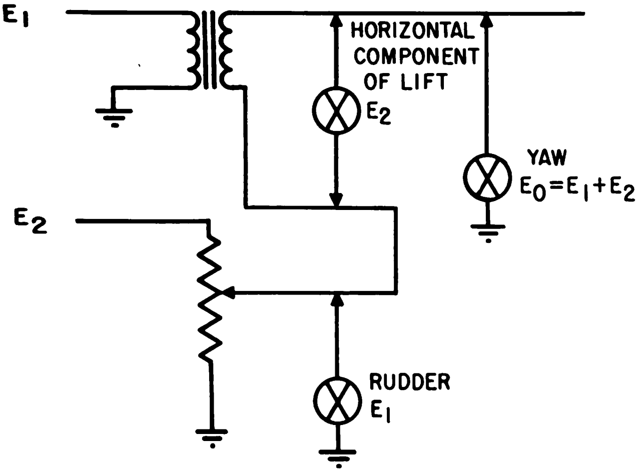


Figure 10-7.—Series addition of two voltages.

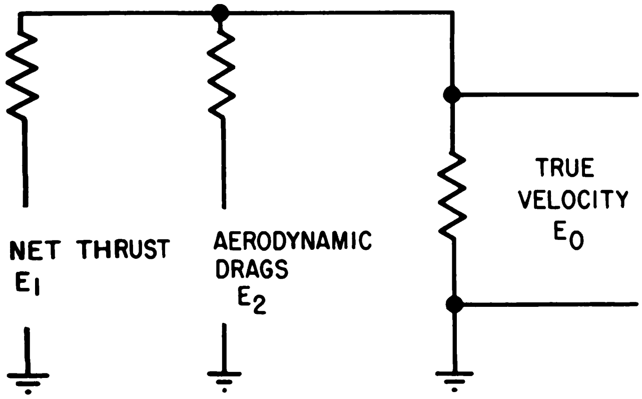


Figure 10-8.—Parallel addition of two voltages.

These are simultaneous linear equations which can be solved for I_2R, the output, in terms of E_1 and E_2, the inputs. Collecting terms give:

$$E_1 = 2I_1R - I_2R + E_2$$

$$E_2 = -I_1R + 2I_2R$$

Multiplying the second equation through by 2 and adding the two equations:

$$\begin{array}{c} E_1 = 2I_1R - I_2R + E_2 \\ \underline{2E_2 = -2I_1R + 4I_2R} \\ E_1 + 2E_2 = 3I_2R + E_2 \end{array}$$

Solving for I_2R:

$$3I_2R = E_1 + 2E_2 - E_2$$

$$I_2R = \frac{E_1 + E_2}{3} = E_{output}$$

If signals of the same polarities are applied as the two inputs shown in figure 10-8, the output will represent the sum of the two. For example, if one is a 4-volt signal and the other a 1-volt signal, the output is 5/3 volts.

If signals of opposite polarities are applied, the output will represent the difference between them. If the two signals are 4 volts and 1 volt, the output is 3/3 or 1 volt with the polarity of the larger.

Electron tube circuits may also be used for the summing operation in analog computers. When two triodes use a common cathode resistor which is not bypassed (fig. 10-9 (A)), the sum or difference of the two voltages applied to the grids appears across the cathode resistor, depending upon whether the applied voltages are in phase or of opposite phase. When a-c voltages of any phase relationship are applied to the grids, the cathode voltage is equal to the vector addition of the two voltages, with the output amplitude proportional to the resultant vector amplitude and the output phase representative of the resultant vector phase angle. The circuit shown in figure 10-9 (B) permits the output to be taken from the common plate load resistor.

Another type of circuit which may be used for summing is illustrated in figure 10-10. Again the input voltages are applied directly to the grids of the triodes. However, in this case the output voltage, e_o, is developed across the plate load resistor (R_L) of V2 and is equal to

$$e_o = \frac{\mu R_L}{R_L + 2r_p} (e_1 - e_2)$$

when V1 and V2 have equal gain.

The output voltage is a proportional sum (or difference based on the inputs) determined by the gain of the stage.

Mechanical summation devices most often use a differential system for computation purposes. Basically, the differential output is the algebraic sum of the revolutions of two independent shafts. The resultant is denoted in the form of shaft rotations of a third shaft as shown in figure 10-11.

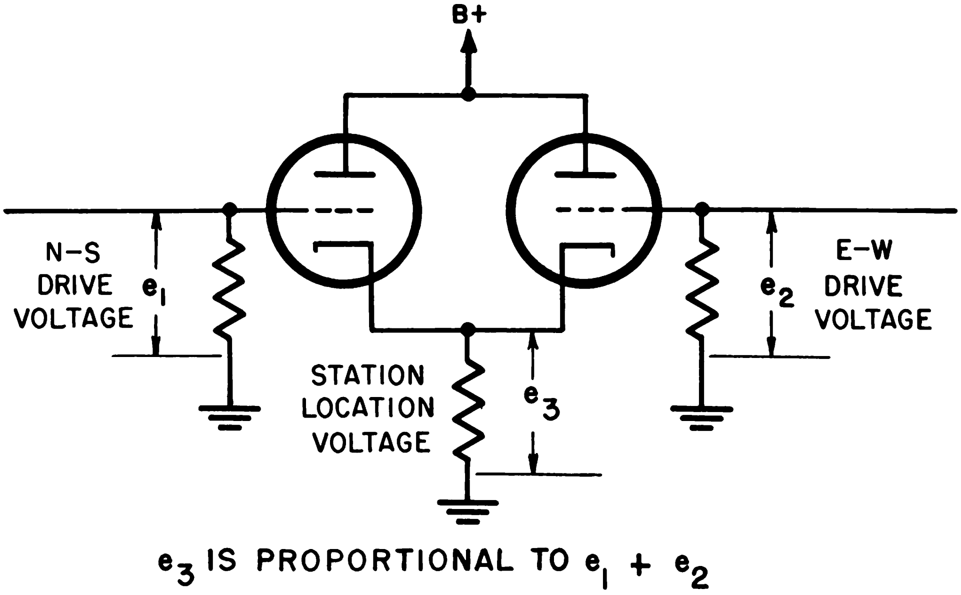


Figure 10-9.—Electron tube vector addition.
(A) Output taken from cathode;
(B) Output taken from plate.

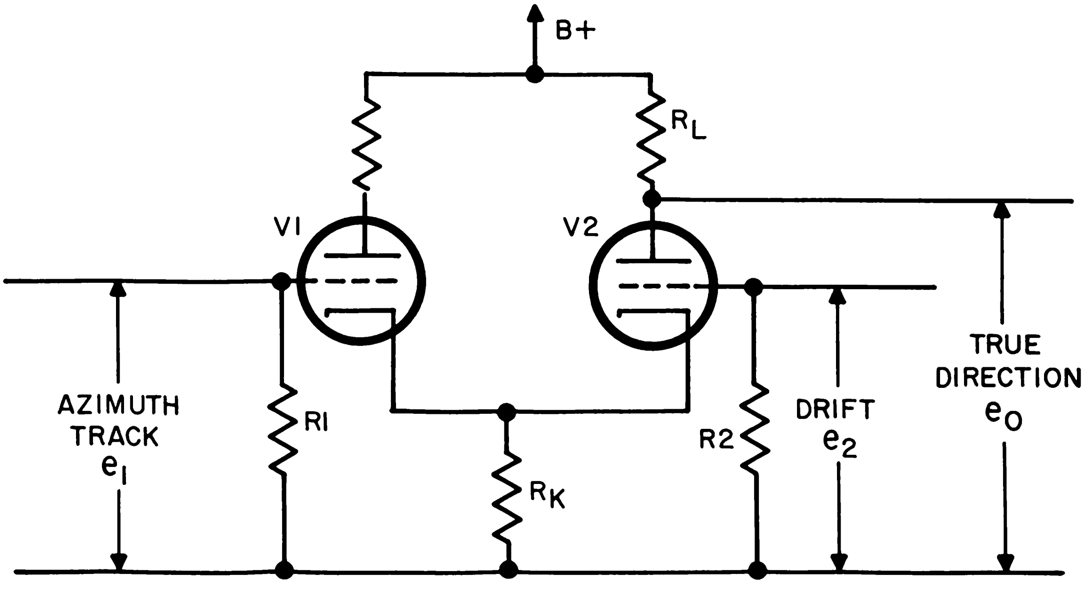


Figure 10-10.—Common cathode difference amplifier.

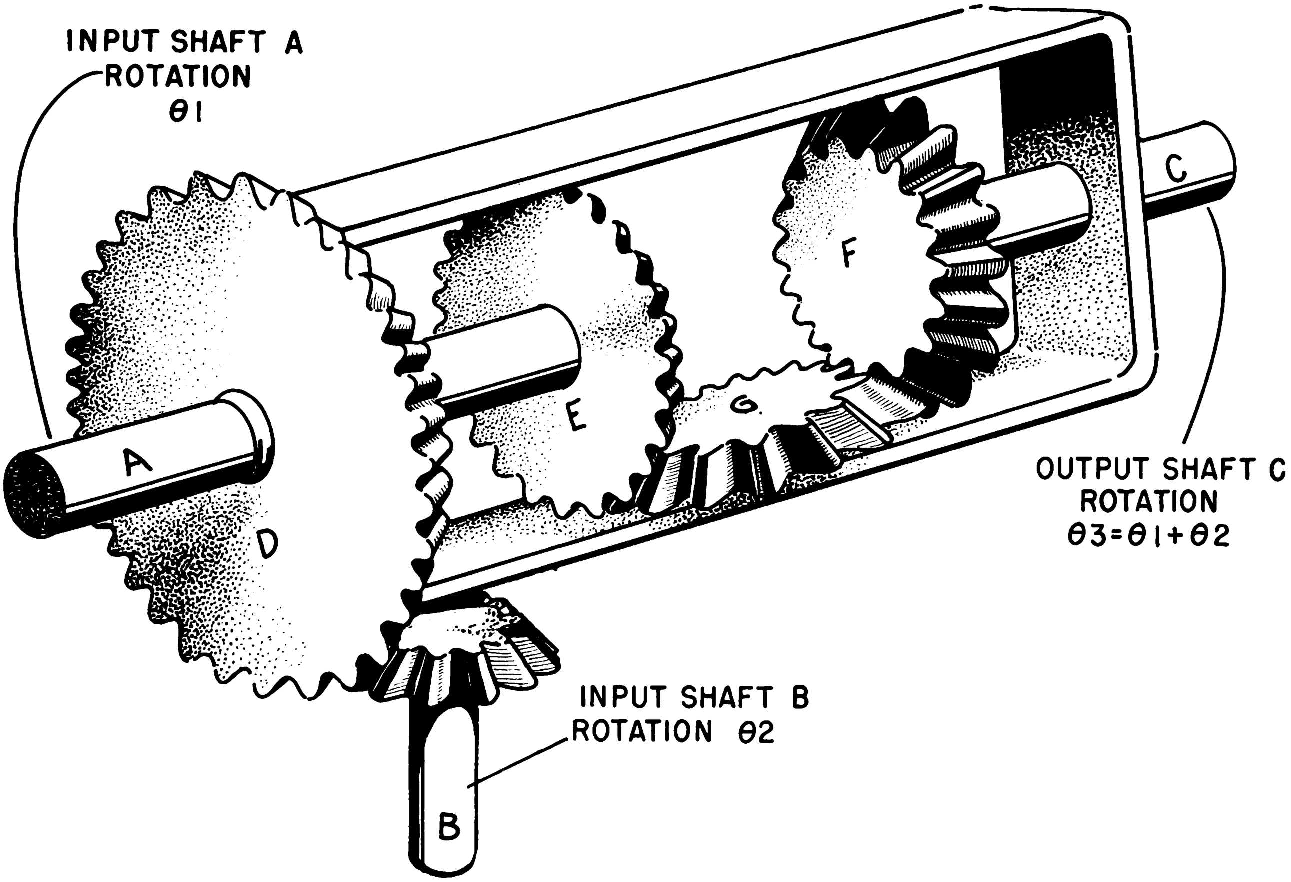


Figure 10-11.—Mechanical differential.

Input shaft A passes through gear D, using it only as a bearing, but connects to and drives gear E. Gear E then drives gears G and F, transmitting the rotation of shaft A (θ1) to shaft C (θ3). Shaft B drives gear D, which is fixed to the outer cage. The cage, in turn, moves idler gear G in a circular orbit. If gear E (shaft A) is held stationary, all of shaft B's rotation will be transmitted to shaft C by idler gear G. Any rotation of shaft A will either add to or subtract from the rotation of shaft B, depending on direction of rotation.

MULTIPLICATION

Multiplication is another of the mathematical operations which may be performed in a computer. It may be performed electronically by electron tube amplifiers or by magnetic amplifiers, electromechanically by potentiometers, or mechanically by devices called multipliers.

Electronic Multiplication

A variety of multiplying circuits have been devised employing electronic amplifiers. However, every linear amplifier is a multiplier. It solves the equation

$$e_o = \mu e_g \frac{R_L}{r_p + R_L}$$

where

e_o is equal to the output voltage

μ is the amplification factor of the tube

R_L is equal to the load resistance

r_p is equal to the internal impedance of the tube

e_g is equal to the input voltage.

Where R_L is very large compared to r_p, the simpler formula $e_o = \mu e_g$ (where e_g is the grid voltage) gives a good approximation of the output voltage.

Theoretically, the input signal voltage would be amplified by the same factor under all conditions. However, the transconductance, amplification factor, and plate resistance may vary with applied voltage and so cause the circuit amplification to vary. Consequently, d-c analog computers employ negative feedback circuits in many cases. Utilizing sufficient amounts of feedback, a high gain amplifier will allow the actual gain of the circuit to be practically a function of feedback and almost independent of tube variations.

Figure 10-12 illustrates a typical triode multiplication circuit. One variable input is applied to the grid as bias to establish the gain of the stage (e_2). The other variable input (e_1) is applied directly to the grid. The output is a proportional quantity equal to the grid signal modified by the gain which is proportional to the variable bias.

Magnetic Amplifiers

Magnetic amplifiers may also be used to multiply one factor by another. The saturable core reactor element in magnetic amplifiers makes the magnetic amplifier easily adapted for multiplying operations. Its amplification can be made proportional to a bias current over a limited range. However, accuracy is limited by variations in magnetic characteristics and winding resistance due to temperature variations. (Refer to chapter 9 of this training course and Basic Electricity, NavPers 10086-A for information on magnetic amplifiers.)

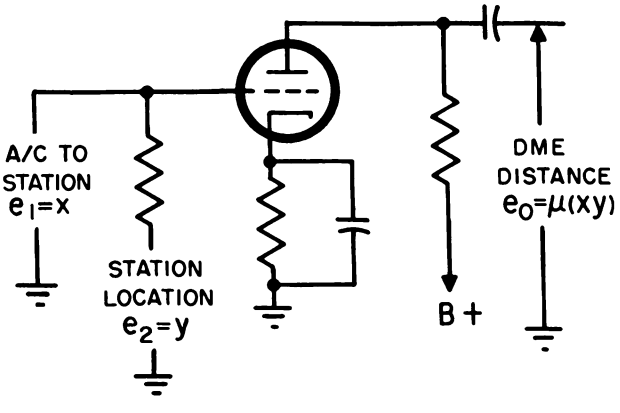


Figure 10-12.—Triode tube used as a multiplier involving two variables.

Electromechanical Multiplication

Some of the electromechanical devices used for multiplication are potentiometers, synchros, and precision variable autotransformers.

Precision potentiometers are frequently used as multipliers in computing equipment because they are accurate, rugged, simply constructed, and inexpensive. They are equally well suited for a-c or d-c applications.

A grounded center tap on the potentiometer winding permits either positive or negative output, depending upon the polarity of the input voltage and the position of the wiper shaft. (See fig. 10-13.) The primary disadvantage of the potentiometer type multiplier is that a quantity cannot be multiplied by a factor greater than unity unless a scale factor is used to convert to a true answer.

Autotransformer multiplication (fig. 10-14) is similar to potentiometer multiplication except

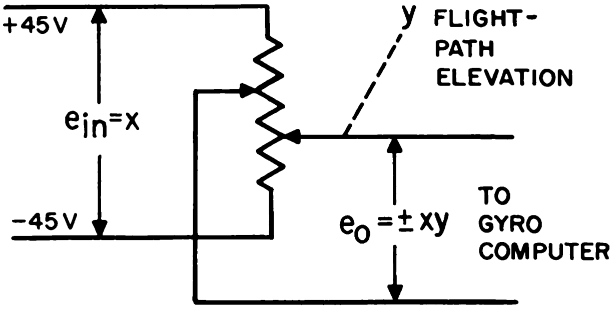


Figure 10-13.—Potentiometer multiplication.

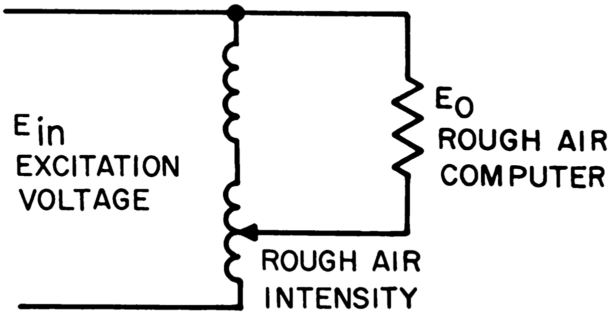


Figure 10-14. Autotransformer multiplication.

that the input voltage must be a.c. and the multiplication factor is not limited to less than one. The input impedance of an autotransformer is high, and its regulation under load variations is very good due to the low d-c resistance of the winding. The low output impedance of the autotransformer permits it to be connected directly to other transformers, potentiometers, or inductive resolvers without intervening isolation amplifiers.

Mechanical Multipliers

These multipliers usually reach a solution through the use of similar triangles. Of the four types in general use—screw, rack, sector, and cam—only the screw type is discussed in this chapter.

The screw multiplier (fig. 10-15) has two inputs and one output. The inputs are shaft values which position the input slide and input rack. The output appears at the output rack which positions the output shaft. Thus the output shaft value is always proportional to the product of the two inputs.

One input gearing is connected to two long screws. These screws pass through the threaded sleeve-like ends of the slotted input slide. As the input gears to the screws are rotated, the two screws turn to position the slide left or right. At

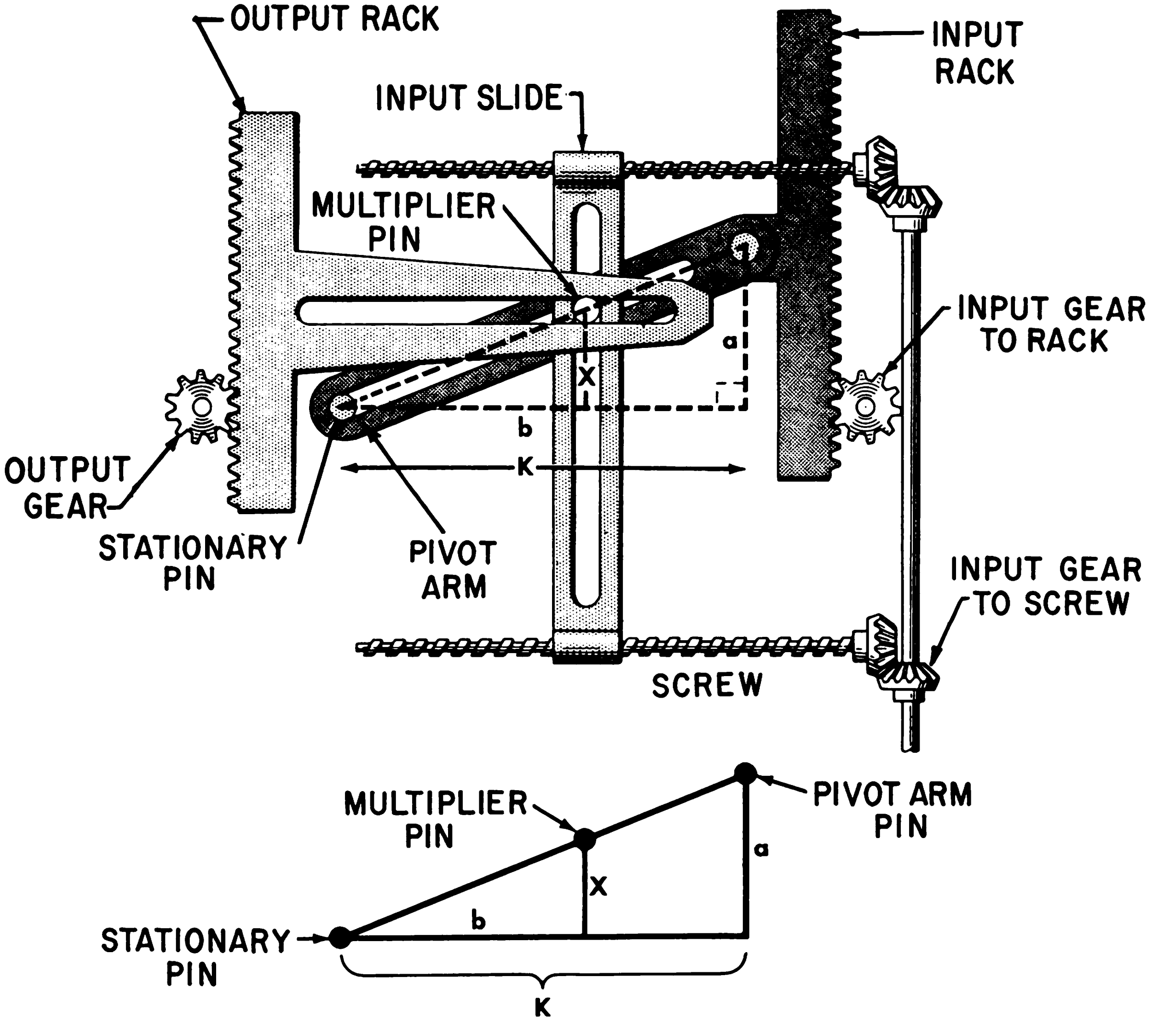


Figure 10-15.—Screw type multiplier.

the same time, the other input positions the input rack up or down, moving the slotted pivot arm around the stationary pin.

The multiplier pin is mounted in the slots of the input slide, pivot arms, and output rack, connecting all three where the slots cross. As the multiplier pin moves with the input slide and pivot arm, it positions the output rack and gear.

Now, consider the multiplier in the zero position shown in figure 10-16. If only the screws are rotated, the input slide moves to the right; but it will not affect the output rack. Similarly, if only the input rack is moved up or down from the zero position, the output rack will be unaffected. This is a reasonable result since any number multiplied by zero is equal to zero.

From this it can be concluded that both inputs must be removed from the zero position for an output. Such a condition is shown in figure 10-15. Notice the triangle superimposed on the device. The value a represents the amount of rack input. The value b represents the amount of slide input. The distance k is fixed and is determined by the location of the stationary pin and input rack.

Because the angles are equal, the triangles are similar. Thus the value of x can be determined if the other values are known.

(Actually, $x = \frac{ba}{k}$.)

This equation shows that the output (x) is always directly proportional to the product of the two inputs. The constant value (k) can be compensated for by the proper choice of input and output gearing for the multiplier. These multipliers can also determine the product of negative values.

DIVISION

Instrumentation of division problems in an explicit form is generally difficult to perform. However, division can be accomplished by taking the reciprocal of the divisor and multiplying it by the dividend. This permits the use of multiplying circuits, which are less complex than dividing circuits.

Electromechanical Division

Division of a variable by a variable (one variable being represented by a voltage, the other by a shaft position) may be accomplished by a variable resistance network. In the variable

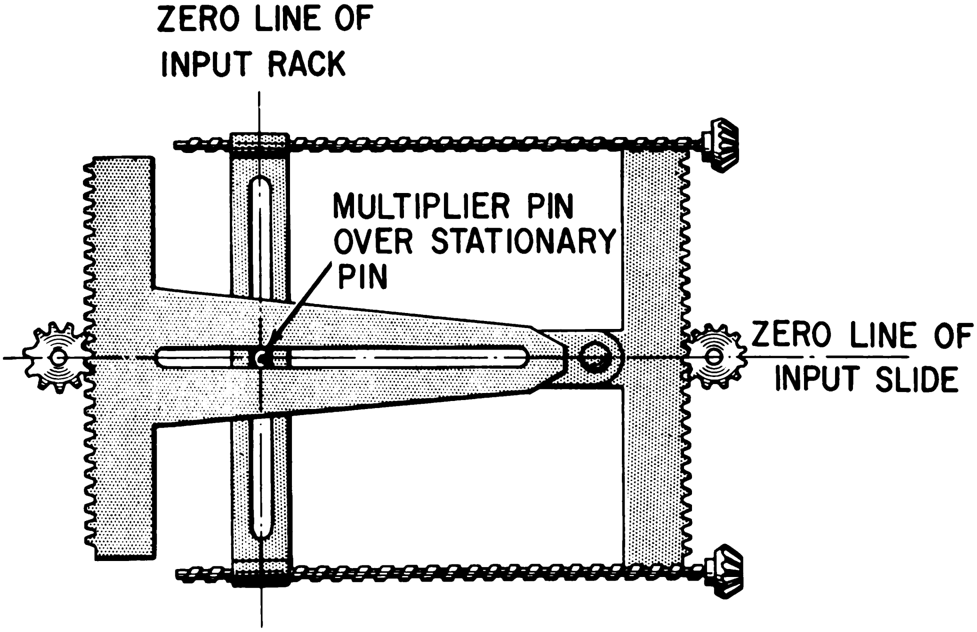


Figure 10-16.—Screw type multiplier in zero position.

resistance network shown in figure 10-17, voltage e_i, which is to be divided (the dividend), is impressed across a potentiometer and resistor series arrangement, R2 and R1. The potentiometer is connected so as to short itself out in proportion to divisor x, which drives the potentiometer arm. Output e_o, consisting of the divided voltage (quotient), is the output across fixed resistor R1. When x is at a minimum, the contact arm of potentiometer R2 is shorting out its entire resistance, producing a maximum output voltage across resistor R1.

As the contact arm of R2 travels toward maximum (dividing factor increases), resistance is added in series with input voltage, reducing the output voltage.

For division of one variable by another variable, both variables being represented by a voltage, a method obtaining a shaft position as output may be used. If voltage y is to be divided by z and output shaft position x represents the quotient, then $x = y/z$. Rearranging this equation, $xz = y$ and $xz - y = 0$. Referring to figure 10-18, variable voltage y is applied in series with the output of a followup potentiometer as input to a servosystem.

The followup potentiometer is excited by the other variable voltage z and has its arm positioned by the motor output of the servosystem. Considering the position of the followup potentiometer arm as x, the output of the followup potentiometer is its excitation voltage modified by its arm position or xz. Therefore, the servoamplifier has two voltages (y and xz added in series) applied to it. The servoamplifier output then drives the servomotor which moves the followup potentiometer arm in such a direction as to cause the input to the servoamplifier to go to zero, thus halting rotation of the servomotor. The two voltages, added in series and applied to the servoamplifier, are then equal and of opposite phase for a resultant voltage of zero, or $xz - y = 0$ as desired. (See fig. 10-18.)

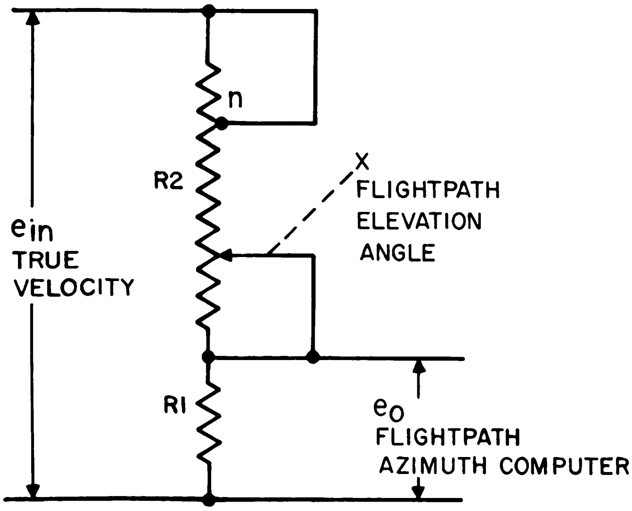


Figure 10-17.—Variable resistance division network.

Electronic Dividers

Electronic division can be performed by inserting a vacuum tube in place of the potentiometer in the circuit shown in figure 10-17. The plate resistance of the tube is varied by the voltage applied to the control grid. Figure 10-19 illustrates the circuit of an electronic divider. The cathode resistor performs the same function as R1 in figure 10-17. As in other electronic circuits, the circuit must be operated within limits determined by its components.

POWERS AND ROOTS

The solution of many problems requires the use of a device capable of raising terms to a power or extracting a root. The usual case involves raising to the second power (squaring) or extracting the square root, but theoretically, practically any exponent value may be used.

A common method of squaring with electromechanical devices is found in the ganged potentiometer multiplier. This device simply carries the single potentiometer multiplier one step further.

A typical unit of this type is shown in figure 10-20. In this figure, the problem to be solved is shown by the equation $y = x^2$, where y is represented by the output voltage e_o and x is the shaft position of the ganged potentiometer. The voltage across R1 corresponds to the maximum value of x, so that the voltage at the arm of the potentiometer is always directly proportional to the actual value of x. In this case, 100 volts was selected as the input and x equals 50 volts (the number to be squared). This is applied to the top of R2 where it is multiplied by the setting of x which again equals 50. The output voltage, 25 volts, is then proportional to the actual value of x^2 since the output of R1 (ex) has been multiplied by x. Thus, ex times x equals ex^2. When converting the proportional value to the true value, the proper scale factor must be used

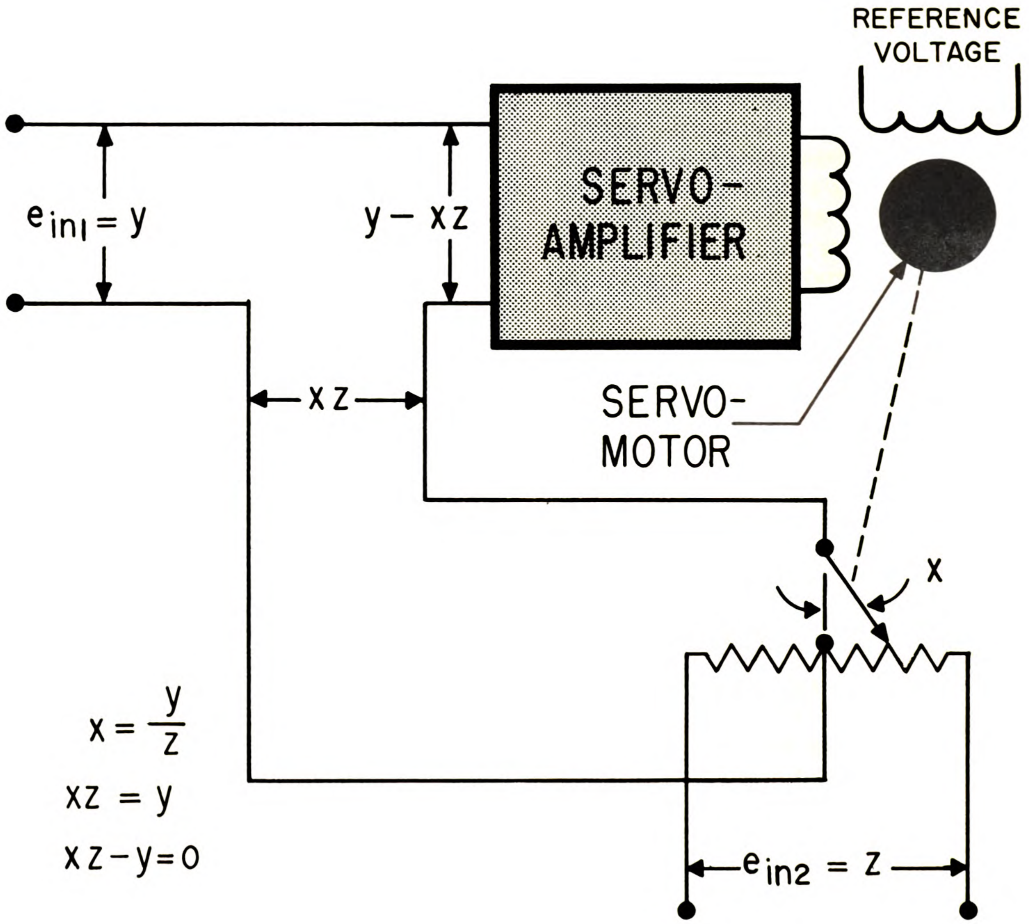


Figure 10-18.—Division of a variable by a variable.

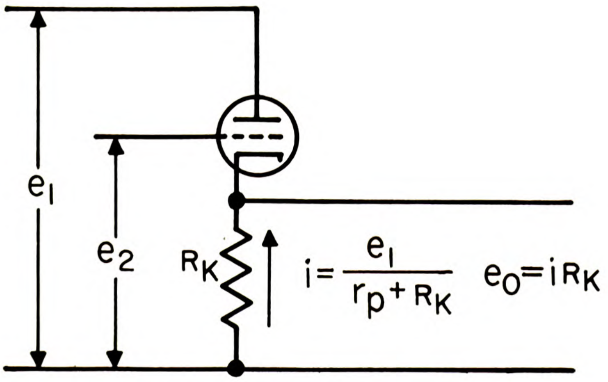


Figure 10-19.—Electronic divider circuit.

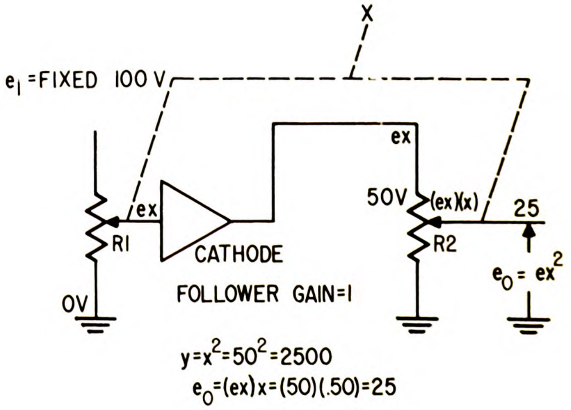


Figure 10-20.—Powers by successive multiplication.

(in this case, 100). The circuit may be used for cubing purposes by the addition of another potentiometer section ganged to the first two.

An electronic method of raising to a power may be found in the squaring amplifier. This consists of a paraphase amplifier driving push-pull triode amplifiers. The output is proportional to the square of the input and for true value calculations, the proper scale factor must be included.

The root of a term may be extracted by either electronic or electromechanical devices. In fact, any device capable of producing a result which is proportional to either a term raised to a power or to its reciprocal can be used to produce roots.

An electromechanical device for extracting the root of a term or number is the servomechanism shown in figure 10-21. The normal equation for root extraction is $y = \sqrt[n]{x}$. This may be written as $x - y^n = 0$ by raising both sides to the nth power and transposing the x term. The equation may then be recognized as the equation for a servomechanism in which the x term represents the input, the y term the followup, and 0 is the error when the x and y^n terms are of equal value.

If the value assigned to n is 2, the equation is then $x - y^2 = 0$. The servo is then adjusted so that the followup value, y^2, is equal to the input value, x. The value of y, which is picked off the first followup potentiometer (prior to squaring) is then equal to the square root of x.

TRIGONOMETRIC FUNCTIONS

Trigonometric processes can be carried out with inductive resolvers, potentiometers, or all-mechanical devices. Electronic networks consisting of RC combinations are also sometimes used to perform such functions as vector addition. Although computations most often used involve sine and cosine values, the remaining trigonometric functions (tangent, cotangent, secant, and cosecant) may be computed based on the sine and cosine.

Inductive Resolvers

The inductive resolver is one of the most common electromechanical devices used to generate trigonometric functions. It is basically a right triangle solver using windings to represent the sides and magnetic flux to represent the hypotenuse. The shaft rotation corresponds to one of the angles of the right triangle to be solved.

The resolver is constructed with both rotor and stator having two sets of windings oriented 90° from each other as shown in figure 10-22. Because of the construction, the resolver may be utilized in two ways: to resolve a single voltage into two components, and to combine two voltages into their vector sum.

In the summing operation, in phase inputs are fed to the windings marked P1 and P2 (fig. 10-22).

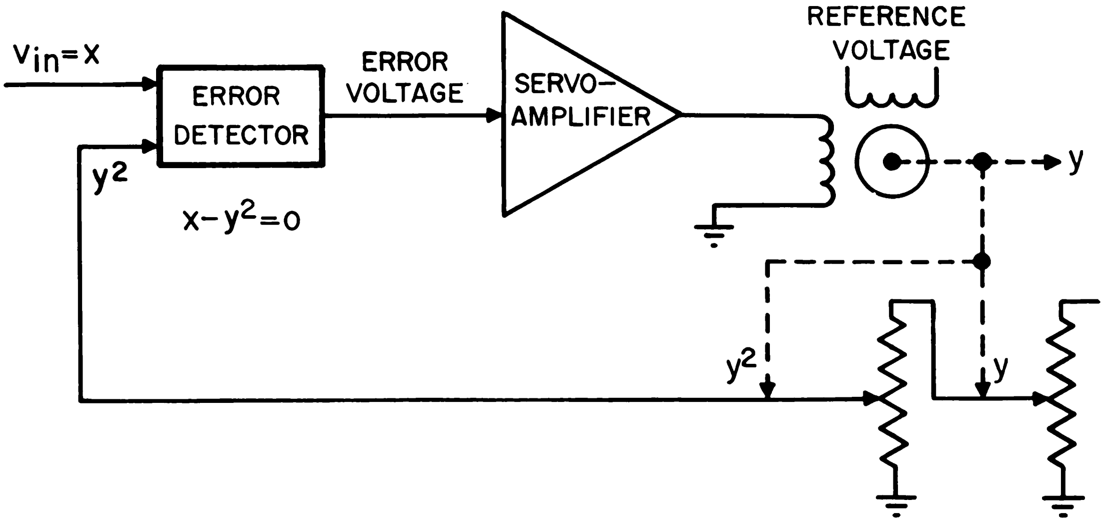


Figure 10-21.—Square root servomechanism.

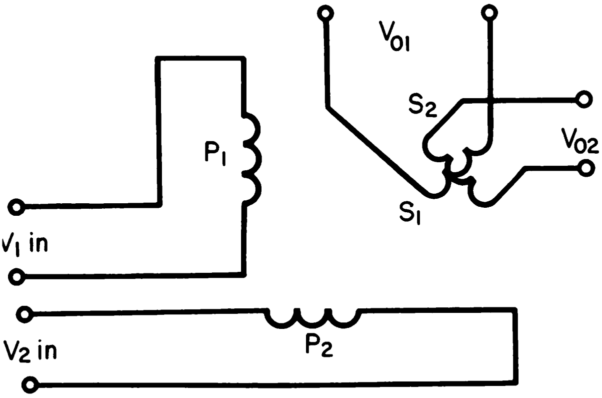


Figure 10-22.—Inductive resolver diagram.

The output may then be taken off winding S1 and is proportional to the square root of the sum of V1 squared plus V2 squared. (S2 remains disconnected.)

$$E_0 = \sqrt{V1^2 + V2^2}$$

If the angle is other than 45°, the output will be less than maximum.

In the resolving operation, one input winding is disconnected and both rotor output windings are used. The outputs then involve the sine and cosine functions. For example, if a voltage is fed to P1, the output taken from S1 equals the input times the sine of the angle between S1 and P1 and the output from S2 equals the input times the cosine of the angle between S2 and P1. Thus,

$$V_{01} = V_{1in} \text{ x } \sin \theta$$

$$V_{02} = V_{1in} \text{ x } \cos \theta .$$

Figure 10-23 illustrates the action of the inductive resolver for three different shaft positions.

Since resolvers are low-impedance devices, isolation or booster amplifiers are usually used as driving circuits. These have the advantage of being able to correct for any phase shift which might occur in the resolver. However, since resolvers operate with only a-c voltages, they cannot be used with d-c analog computers.

POLAR TO RECTANGULAR COORDINATE TRANSFORMATION.—If the position of a point or object is defined by a vector, the polar dimensions of the vector may be converted to rectangular coordinates as shown in figure 10-24 (A). The vector quantities of distance (r) and angle (θ) may be resolved to horizontal and vertical distances, x and y respectively, with a 2-phase inductive resolver.

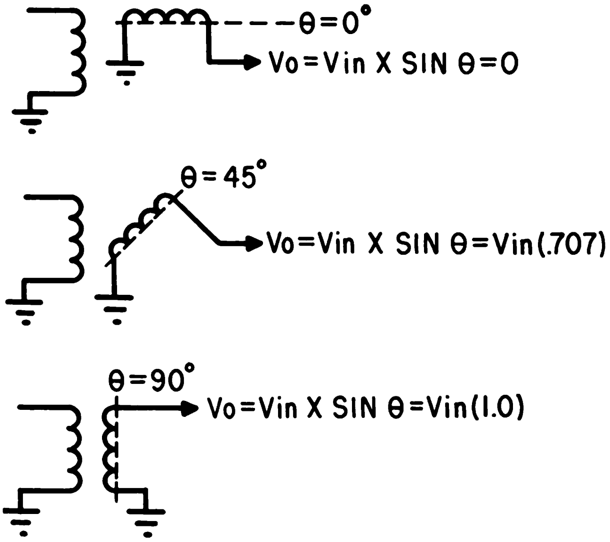


Figure 10-23.—Inductive resolver action.

By feeding a voltage representing the distance r into the one stator winding and rotating the rotor shaft in a way that corresponds to θ, voltages representing x and y are produced at the rotor windings (fig. 10-24 (B)).

RECTANGULAR TO POLAR COORDINATE TRANSFORMATION.—Often the conversion of x and y information to a single voltage vector representing range (r) and bearing (θ) is necessary. Polar coordinates may be obtained from rectangular coordinates by an inductive resolver and a servomechanism (fig. 10-25). Voltages representing the x and y coordinates are fed to the respective stator windings. When the rotor is rotated so that one of its windings is parallel with the resultant magnetic field of the stators, a vector voltage of magnitude $r = \sqrt{x^2 + y^2}$ is induced in this winding. In this condition, the second rotor winding is perpendicular to the resultant magnetic field of the two stators; hence zero voltage is induced in it. Since this is

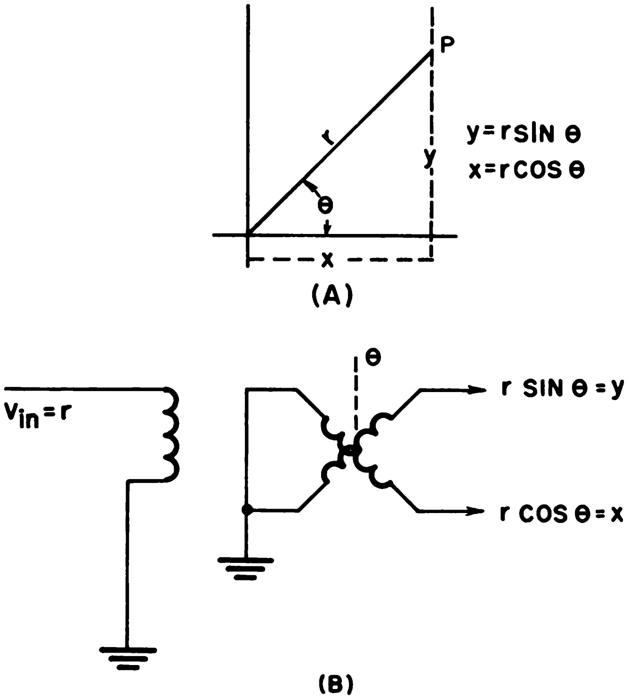


Figure 10-24.—Polar to rectangular coordinate transformation.

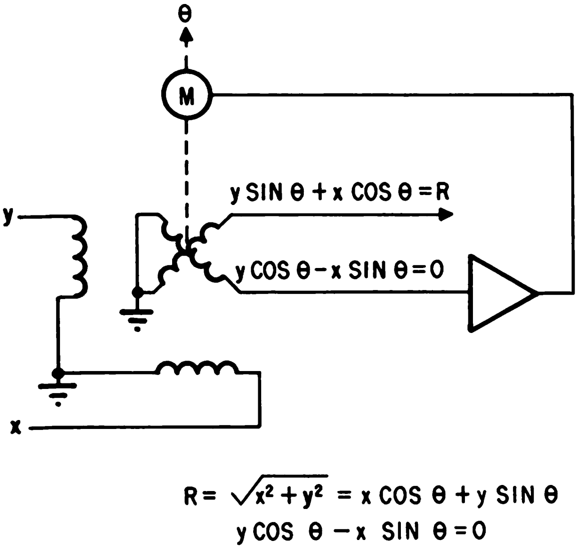


Figure 10-25.—Rectangular to polar coordinate transformation.

true, the second rotor winding voltage is connected as an input to the servo. The servomotor drives the rotor shaft until zero voltage is induced in the second winding, at which point the true vector voltage is produced at the first rotor winding. The rotor shaft position then represents the angle θ .

The use of the inductive resolver as an error detector introduces a disadvantage. The fact that the error signal is proportional to the range voltage as well as to the angular rotation introduces a variation in servo loop gain. This may make the servo response progressively insensitive as r decreases. To compensate for the variation in gain, automatic gain control circuits can be added. When the variable r is low, the gain is made high; when r is high, the gain is lowered.

A potentiometer with an output proportional to 1/r can be used to control the servoamplifier gain. Another method employs a variable gain amplifier in which the grid bias of the tube is made proportional to the range voltage by rectifying r and using it as grid bias.

Sine-Cosine Potentiometers

Output voltages proportional to the product of the input voltage and the sine of the angle through which a shaft is rotated can be obtained from a potentiometer specially designed for that purpose. The sine-cosine potentiometer is a rectangular flat card wrapped with closely spaced, uniformly wound resistance wire. The card is mounted on a shaft and can be rotated. A pair of wipers mounted on the potentiometer case with contacts diametrically opposite each other will trace a circular path on the card as it is rotated.

If two pairs of wipers displaced 90° from each other are included, both sine and cosine functions can be obtained. (See fig. 10-26.) Either a-c or d-c voltages may be applied.

With a balanced input voltage, as shown in figure 10-26, the center of the card is zero (ground potential). Voltages at wiper contacts for various shaft positions are shown in the following:

Angle θ	A (sine θ)	B (cos θ)	C (-sin θ)	D (-cos θ)
0°	0v	100v	0v	-100v
30°	50v	-86.6v	-50v	86.6v
45°	70.7v	-70.7v	-70.7v	70.7v
90°	100v	0v	100v	0v
180°	0v	-100v	0v	100v

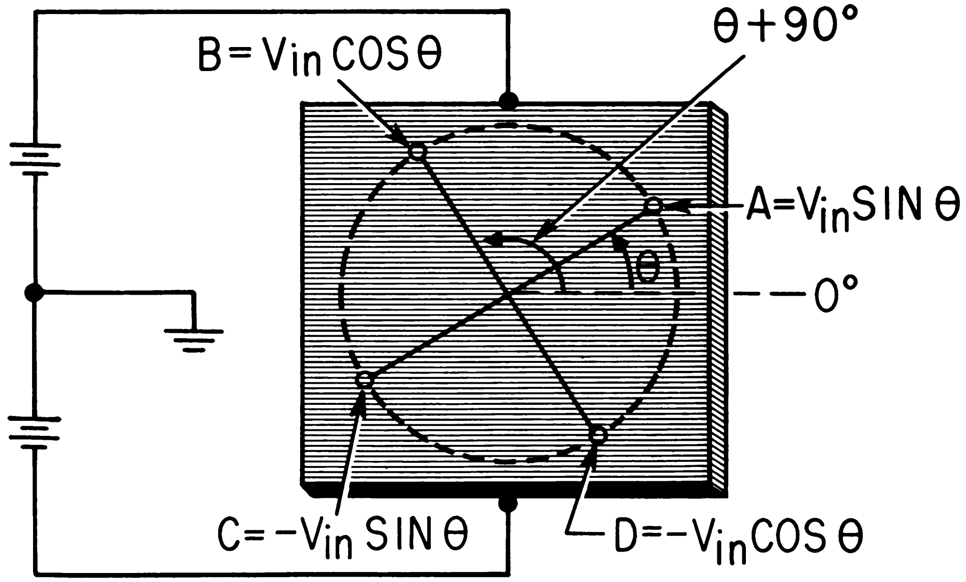


Figure 10-26.—Sine-cosine potentiometer.

Another widely used type of sine-cosine potentiometer incorporates a tapered card resistance element.

Scotch Yoke Mechanism

The scotch yoke mechanism is a mechanical device used to produce motions proportional to the sine or cosine of the input angles. (See fig. 10-27.) As the crank rotates, the slide is displaced vertically within the channel of the output shaft. As the output shaft moves from side to side, its linear horizontal displacement is proportional to the sine of θ. Parts must be held to extremely close tolerances to avoid inaccuracies caused by clearance between the slide and channel.

NONLINEAR FUNCTIONS

Logarithmic-Response Networks

In some computing operations, it is more feasible to work with signals that are proportional to the logarithms of the significant factors rather than with signals which vary in direct proportion with the significant factors. This is especially true when the factors in question are large in amplitude. In this case, logarithmic networks are employed in which the output is an approximate logarithmic function of the applied input. An example is shown in figure 10-28. As indicated by the response curve, the input is a current; the output is a voltage. The slope of the response curve becomes increasingly flat as the input current increases, thereby providing the essential characteristics of logarithmic resonse.

When the input is applied (fig. 10-28), current flows through R1, producing an output voltage proportional to the current (E = IR). As the current increases, the voltage drop across R1 also increases until it becomes great enough to bring CR1 (a crystal diode) into conduction. In this condition, R3 is effectively placed in parallel with R1 because of the low internal resistance of CR1 when in the conducting state. The effect is to lower the total resistance and to produce less voltage drop across the output resistor for a given increase in input current. (This accounts for the bend in the response curve at point a.) The slope of the curve is progressively reduced as additional rectifiers come into conduction. It should be noted that by increasing the number of rectifiers, a more perfect logarithmic curve is obtained.

Nonlinear Circuit Elements

Often the relationship between two variables cannot be expressed by any of the mathematical operations described in the preceding sections.

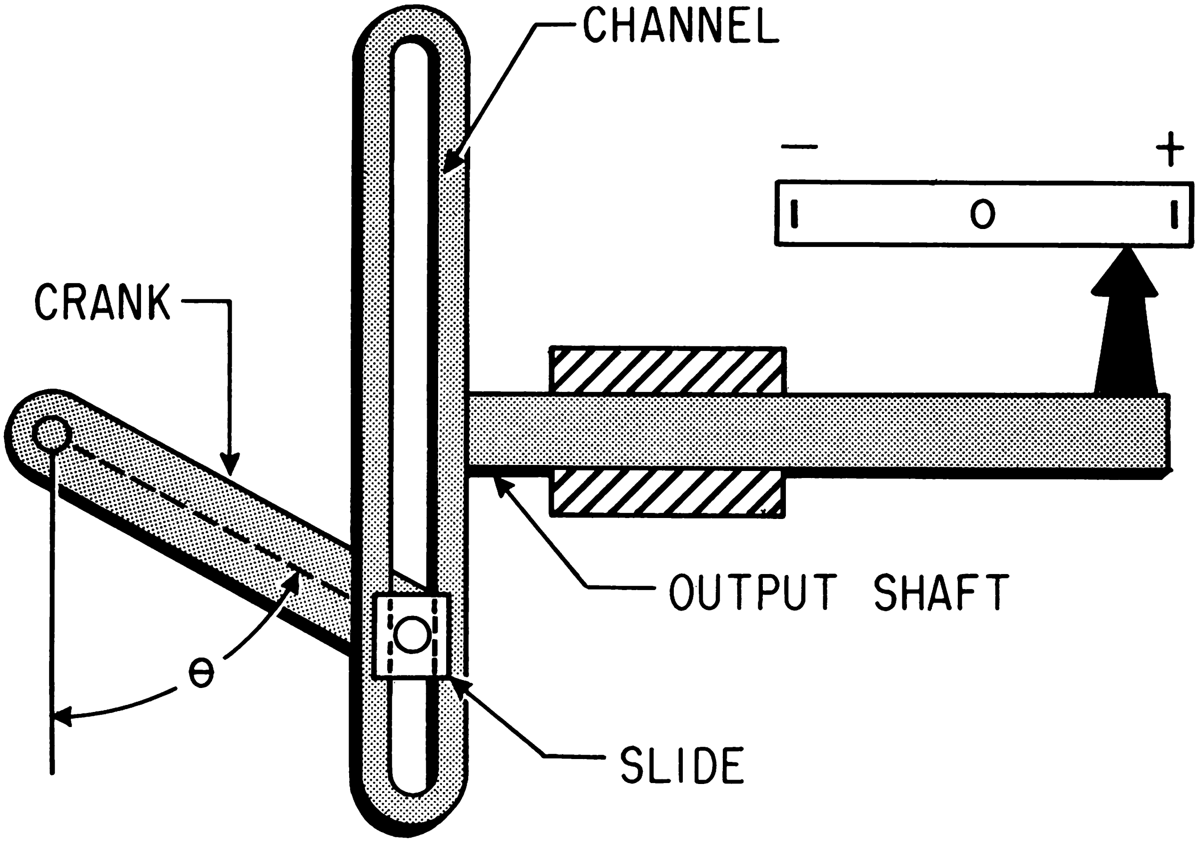


Figure 10-27.—Scotch yoke mechanism.

In these cases, circuit elements of special design are employed to produce the desired output. These elements include cams, noncircular gears, and functional potentiometers. When it is necessary that the output vary with two inputs, three-dimensional cams are often used to derive the required output. In addition to the nonelectronic elements mentioned above, there are various electronic devices designed for generating nonlinear functions. However, in electromechanical computers functional potentiometers are generally employed.

There are several methods of designing potentiometers with nonlinear outputs—by use of shaped cards, spaced windings, tapped windings with shunts, tapped windings connected to multiple voltages, and by use of cams. These methods are based on three different basic approaches: by making the winding nonlinear; by adding taps to a linear winding and introducing the nonlinear function externally; and by making the wiper motion nonlinear. These methods are discussed in detail in another section of the chapter.

DIFFERENTIATION

Differentiation and integration are mathematical operations involving rates. The process of determining the rate of change of one variable with respect to another is called differentiation; the process of determining the sum of many minute quantities is referred to as integration (generally interpreted broadly as finding the area under a curve).

Electronic Differentiation

The rate at which an input voltage is changing can be obtained from a simple series-connected resistor and capacitor combination. A means

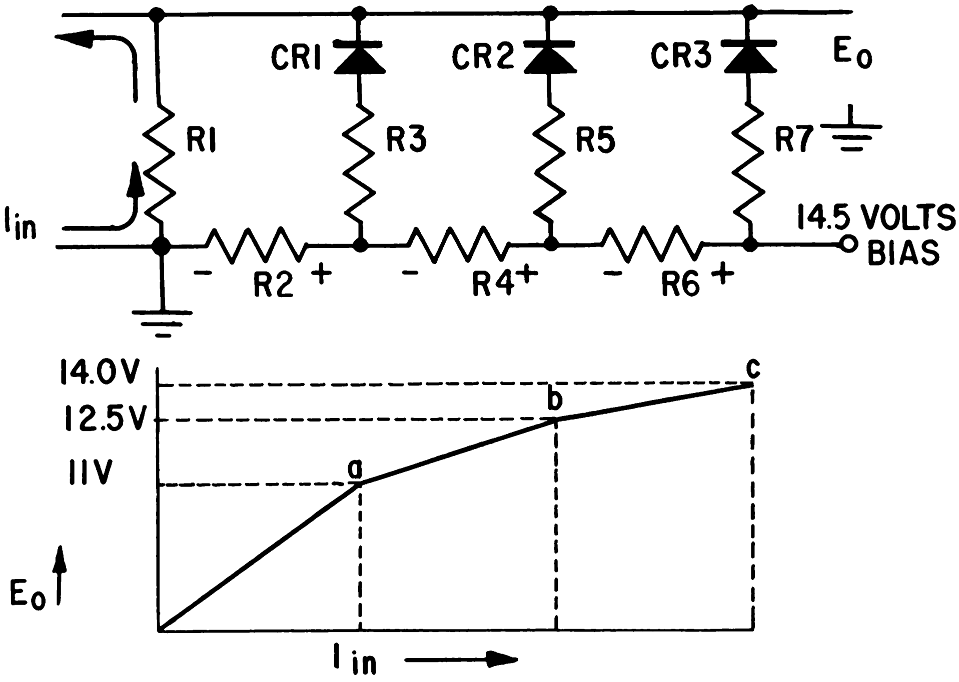


Figure 10-28.—Typical logarithmic output network.

of differentiation superior to the common RC circuit is shown in figure 10-29. The circuit shown is a feedback-amplifier differentiator which attains its superiority by deriving an output voltage from the input in a shorter time period and with greater accuracy. (Prior to an explanation of this circuit, the reader is requested to review the principles of feedback amplifiers as discussed in Basic Electronics, NavPers 10087-A.)

In this particular application (fig. 10-29), the following conditions are established:

1. The amplifier is biased to operate near the center of its linear range and draw no grid current in any part of the operating cycle.
2. The grid voltage is near ground potential and varies only slightly with input voltage due to feedback action.
3. With the grid voltage held almost constant, any change in plate voltage due to input variation appears across both the plate load and the feedback resistor and causes a corresponding change in current through both.

Since almost identical waveforms appear across both resistors (fig. 10-29), the output voltage can be conveniently expressed in terms of the feedback resistance and the change in current through it. Thus: $E_o = - \Delta iR_{fb}$ (The negative sign indicates a polarity reversal.)

Consider the action of the circuit with a constantly changing input applied. For simplicity, a back-to-back sawtooth, starting downward from its apex, is used. As the negative going signal starts downward, electrons from the grid side of C1 (fig. 10-29) start to flow through R_{fb} causing a drop in the grid voltage. This action reduces the plate current, thereby increasing plate voltage. A portion of the latter is fed back to the grid, causing it to rise. But, since the feedback is only a small portion of the plate signal, the grid does not regain its initial value. The grid and plate reach a state of equilibrium almost instantaneously and remain so as long as the current through R_{fb} is constant, or for the duration of the linear downward slope of the input.

When the input direction is reversed, the plate voltage decreases due to the attempt of the grid voltage to rise. The feedback is then opposite to its previous polarity and tends to hold the grid again at its new voltage. As long as the linear rise continues, the decreased plate voltage remains constant as does the increased grid voltage. The output waveform, taken off either the plate load or the feedback resistor, is consequently a square wave.

Mechanical Differentiation

The derivative of a shaft rotation can be obtained by the mechanical ball-disk differentiator illustrated in figure 10-30. The device differentiates the quantity y in respect to t (time) and produces an output proportional to the rate of rotation.

Basically, the unit consists of a flat rotating disk, driven by a constant-speed motor; a ball and carriage assembly; a roller; and a differential gear assembly. In the illustration, the input (y) feeds the differential gear which receives a simultaneous input from the roller. The constant-speed motor drives the disk which, in turn, drives the balls which rotate the roller. The output of the differential gear is in the form of a shaft rotation which positions the carriage in the direction necessary to shift the position of the balls to increase or decrease the speed of the roller as needed. The ultimate output is taken from the carriage and positions the shaft to indicate the rate of rotation of the input shaft.

In practice, the unit (fig. 10-30) may be calibrated by injecting zero y input and setting the output indicator on zero. The balls should

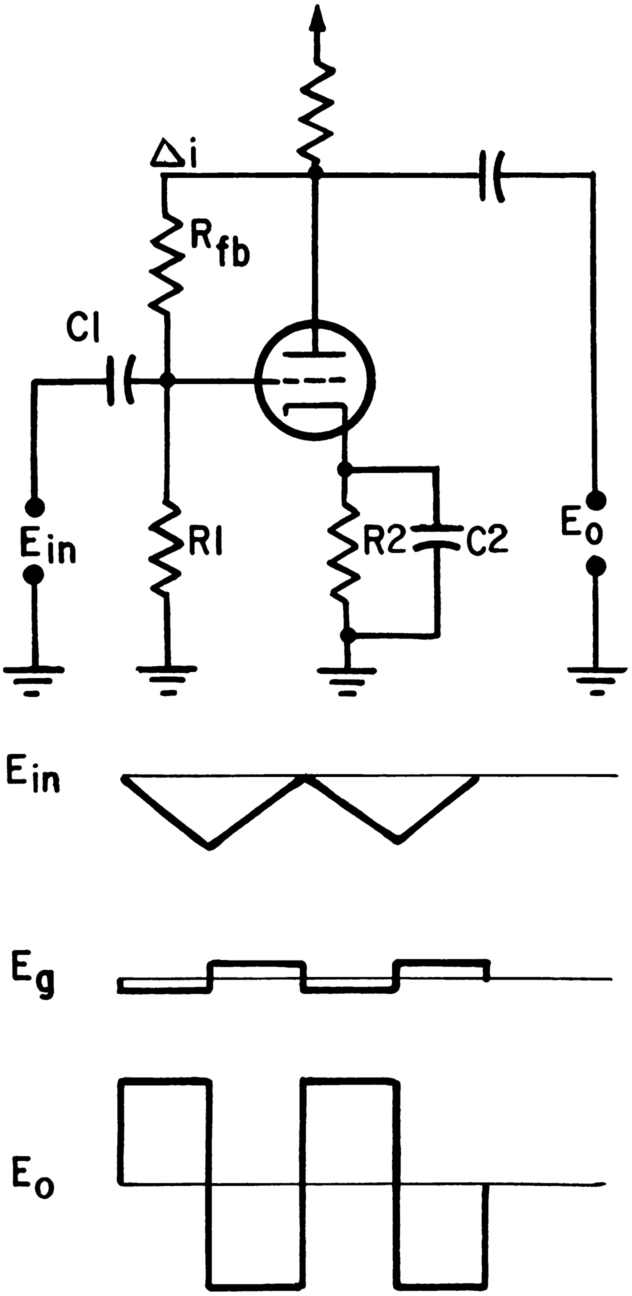


Figure 10-29.—Differentiating feedback amplifier.

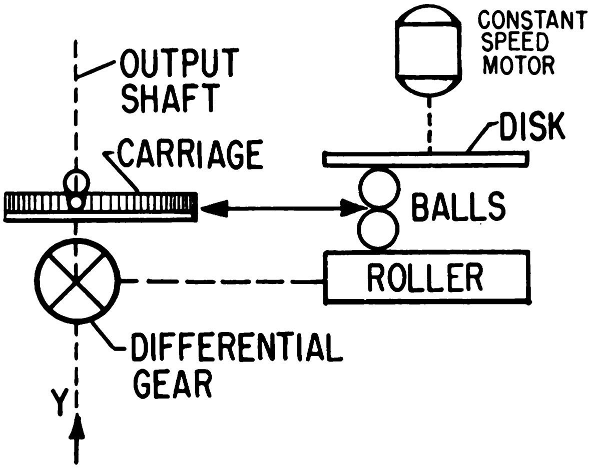


Figure 10-30.—Ball-disk differentiator.

then be directly under the center of the rotating disk, causing the roller to remain still and resulting in zero input to the differential assembly. As a y input is injected, the differential gear goes into action and imparts motion to the carriage, which moves the balls out from the center of the disk. The resultant roller motion is applied to the differential gear. This motion, when combined with the input, acts as a feedback which zeros the output of the differential. Consequently, the output shaft stops at a position indicative of the rate of rotation of the input.

INTEGRATION

As previously noted, integration is the process of summing up an infinite number of minute quantities. In most practical applications, integration is the process of summing certain quantities in respect to time. For example, taking the integral of velocity between certain time limits results in the distance traveled. Thus, in an automobile, the speedometer is a differentiator, while the odometer is an integrator.

The summing of many minute quantities is analogous to finding the area under a curve. In the case of a step function, the input wave may be considered as a rectangle having one side variable with time. In figure 10-31 (A), this may be seen to be the solid line, Y1, plotted on a graph of velocity versus time. The distance traveled is equal to the velocity multiplied by the time. In the diagram, this is shown by the numerical value of the area under the curve (which in this case is a rectangle). The area of the rectangle is equal to the height times the length and thus the area is proportional to the distance, which is the product of time and velocity. On the time-distance diagram of the figure, the sloping line (X1) shows the distance traveled at any instant of time. The larger the amplitude of the step input, the steeper the slope of the line. This is shown by the larger step input (Y2) on the time-distance chart.

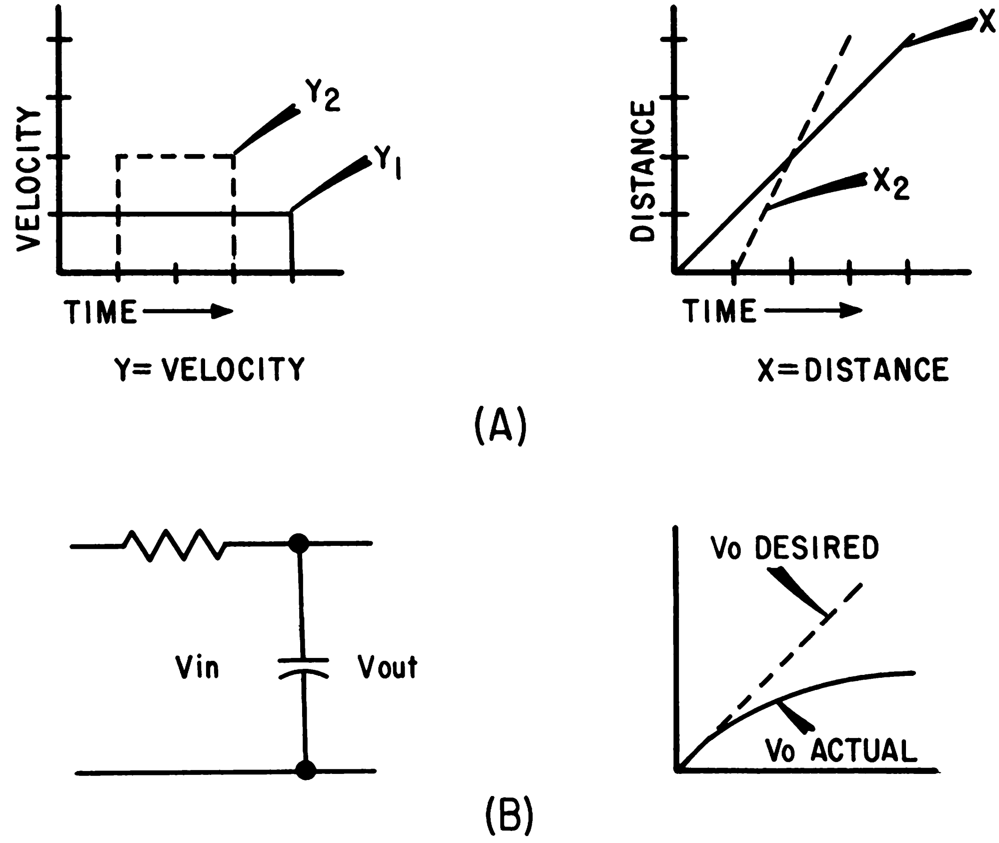


Figure 10-31.—Integration of area.

Electronic Integrators

Although the distance traveled must continue to increase as long as there is a positive value of velocity, in electronic integrators when the input is a voltage of x value, the circuit components limit the maximum value of the output. Thus, in figure 10-31 (B) where the input is V_{in} the actual output (V_o) differs considerably from the desired output because of the R and C values used in the circuit shown.

An integrator circuit utilizing a feedback amplifier is shown in figure 10-32. While bearing certain similarities to the differentiating amplifier, the significant exceptions are the input and feedback components. Note that in this case, the feedback element is a capacitor and the input is a large value resistor. These two components (the resistor and capacitor) perform the integrating function while the amplifier operates to improve the response and linearity. The use of a large input resistor (compared to the grid-to-ground resistance) allows the grid to be maintained at an almost constant potential when an input signal is applied.

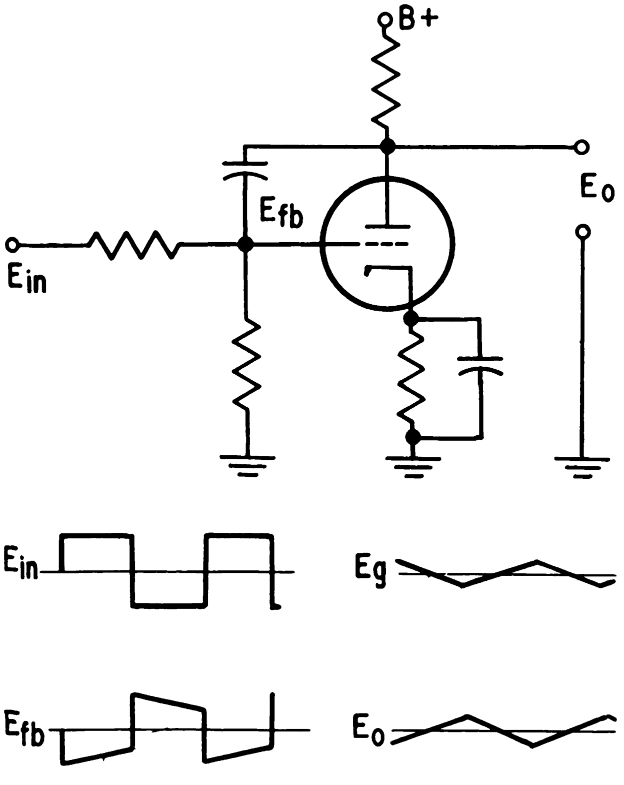


Figure 10-32.—Integrating amplifier.

The output is based on the rate of charge or discharge of the feedback capacitor. The amplifier functions to maintain the charge, or discharge, of the integrating capacitor in the linear portion of the RC curve. The net effect is that the capacitor voltage does not oppose the input voltage and the capacitor charging current depends directly upon the input signal voltage. Waveforms applicable to the circuit are shown below the circuit diagram (fig. 10-32).

Mechanical Integrators

A mechanical integrator is a device whose major function is to add an infinite number of minute sums, exactly as an electronic integrator. The most common example is the odometer (mileage indicator) of an automobile, wherein the numerous changes in rate or velocity are added to give the distance traveled.

A common naval application can be found in the ball-disk integrator often used in operational trainers to establish the position of the simulated aircraft in relation to a specified reference point. In order to give a continuous indication of position, two integrators must be used: a north-south integrator and an east-west integrator. The vector sum of the action of these two integrators establishes the range and bearing of the aircraft from the reference point. Since both integrators are identical, only the action of the north-south unit need be discussed.

In order to establish the position of the simulated aircraft on the N-S axis, a component of groundspeed in the N-S axis must first be predetermined. This component is derived from heading, airspeed, windspeed, and wind direction supplied to the unit. The inputs to the integrator are then the N-S axial component of groundspeed, and a time reference. The output is the computation of the position of the simulated aircraft with respect to a reference point.

The most important parts of a ball-disk integrator are shown in figure 10-33. They are a rotatable disk, a cylindrical output roller, and a pair of steel balls which transfer motion from the disk to the roller. The steel balls are restrained by a carriage which runs along a pair of guide rails across the face of the disk. Rotary input motion drives the disk; linear input motion

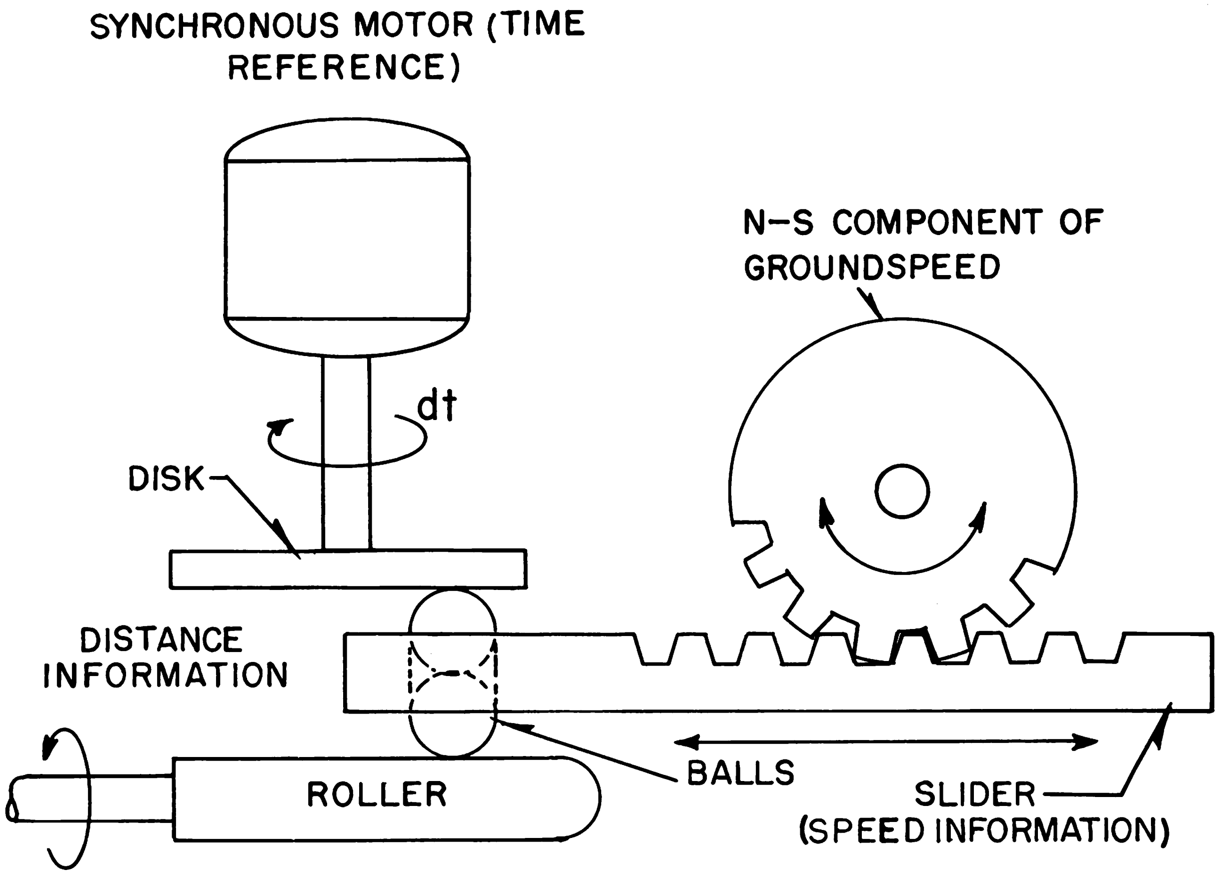

SYNCHRONOUS MOTOR (TIME REFERENCE)
N-S COMPONENT OF GROUNDSPEED
dt
DISK
DISTANCE INFORMATION
ROLLER
BALLS
SLIDER
(SPEED INFORMATION)

Figure 10-33.—Ball-disk integrator.

positions the ball carriage upon the disk; and the roller rotates at a speed proportional to the product of the two input motions.

Time reference is supplied to the unit by a synchronous, constantspeed motor attached to the disk. The N-S axial component of groundspeed is converted to a linear motion by means of a servomechanism and is fed to the ball carriage.

When groundspeed is zero, the ball carriage is positioned in the center of its travel by the servo and the upper steel ball rests in the exact center of the rotating disk. Although the circumference of the disk is rotating rapidly, there is no motion at the exact center of the disk and, therefore, no motion is transferred to the output roller through the steel balls. As groundspeed increases in the north direction, the ball carriage is moved by the servo toward one end of the housing and the upper steel ball begins rotating. Its speed of rotation is proportional to the distance between the center of the disk and the point on the disk at which the upper ball makes contact. Through friction contact, the upper ball rotates the lower steel ball and the latter rotates the output roller.

If groundspeed increases in the south direction, the balls are displaced in the opposite direction, and the direction of rotation of the output roller is reversed. The speed of rotation of the output roller is proportional to both the displacement of the balls from the center of the disk and the speed of the disk. The direction of rotation is dependent on the direction of travel, either towards or away from the reference point. Since the speed of rotation of the output roller is proportional to the N-S groundspeed of the simulated aircraft, the amount of rotation is proportional to the distance traveled from the reference point, providing data on the position of the simulated aircraft at any given instant.

OPERATION OF A TYPICAL ANALOG COMPUTER

As explained in the preceding pages of this chapter, an analog computer usually solves mathematical equations by employing voltages of the proper magnitude and phase to represent the quantities involved. By adding, subtracting, multiplying, or dividing these voltages, a resultant voltage is obtained whose magnitude and phase represent the solution of the equation. The following paragraphs afford an example of how this may be accomplished. The example chosen is not that of a flight trainer computer, but has been selected because the system uses some of the fundamental operations previously discussed. It involves the simulation of a situation with which nearly everyone is familiar; that is, the depletion of fuel in the tank of an automobile as its engine operates.

The approximate quantity of fuel present in the gasoline tank of an automobile is indicated to the driver by the fuel gage on the dashboard. Suppose it is desired to actuate this instrument in a realistic manner in an automobile containing all interior controls but having no actual engine or gas tank. Some of the conditions to be taken into account are stated in the following list:

1. The engine must not "start" unless the ignition key is turned on.
2. When the ignition key is turned on, the fuel quantity gage should indicate a gradual change from the "empty" position to the position indicating the present level of fuel.
3. The starter button must be pressed and held for a short period of time until the engine "fires." This may be longer than usual in cold weather.
4. After the engine is started, the rate of fuel depletion should be proportional to accelerator position. Maximum (wide open) and minimum (idling) rates of consumption must be established.
5. "Starter" and "engine" sounds should be heard. The "engine" shounds should vary with engine speed, and spluttering sounds should be heard just prior to the time the fuel is exhausted. All sounds should then cease.

A computer designed to satisfy the above requirements is shown in figure 10-34. The symbols used in the figure to represent motors, cam switches, gear ratios, etc. are identical to those appearing in the drawings of actual trainer circuits.

The heart of the computer shown in figure 10-34 is a motor-driven shaft labeled fuel quantity shaft. The horizontal portion of the shaft is driven by the motor through a very large gear reduction so that it rotates slowly, requiring 3 hours to rotate through 320° if the motor runs at full speed for the entire time. The quantity of fuel is indicated on a 0-1 milliammeter whose scale has been calibrated to read 0, 1/4, 1/2, 3/4, and full. The voltage across the milliammeter is dependent upon the position of the wiper arm of potentiometer, R8, which is driven at a 1 to 1 ratio by the horizontal portion of the fuel quantity shaft.

The simulated action of filling the fuel tank is accomplished by manually rotating the shaft by means of the fill knob until the shaft reaches its zero-degree stop, at which time the wiper arm of R8 is positioned at the bottom of the potentiometer. A slip clutch allows the main portion of the shaft to be rotated in this fashion without turning the motor through the large gear train.

When the ignition switch, S1, is closed, the filament transformer, T2, is energized and the cathode of V1 gradually heats so that the rectified voltage across the filter capacitor, C2, reaches its maximum value (150 volts) in about a half minute. Assuming that the tank is full, the arm of potentiometer, R8, is at its lowest point. One hundred and fifty volts d.c. is applied across R8 (150K) and the fuel quantity meter so that the reading of the latter, when the ignition switch is turned on, creeps up from E (empty) to F (full), since 150 volts across 150K results in a current of one milliampere.

The starter button, S2, is a spring-returned, momentary contact switch. When held in the closed position, 28 volts d.c. is advanced to the starter noise generator. Details of the latter circuit are beyond the scope of this introductory discussion, but it may be assumed that the 28 volts applied from the starter button is sufficient to overcome a negative bias applied to a suitable audio oscillator which then generates the characteristic sound of the engine starting.

Holding the starter button closed applies voltage to the thermal element of the starter-delay relay, K1, and the contacts of this relay close if the starter button is held closed for a sufficient time. Upon closure of the starter-delay relay, 28 volts are advanced to energize the engine-on relay, K2. If the ignition switch has been closed, a holding voltage is applied to K2 through the middle set of contacts on the

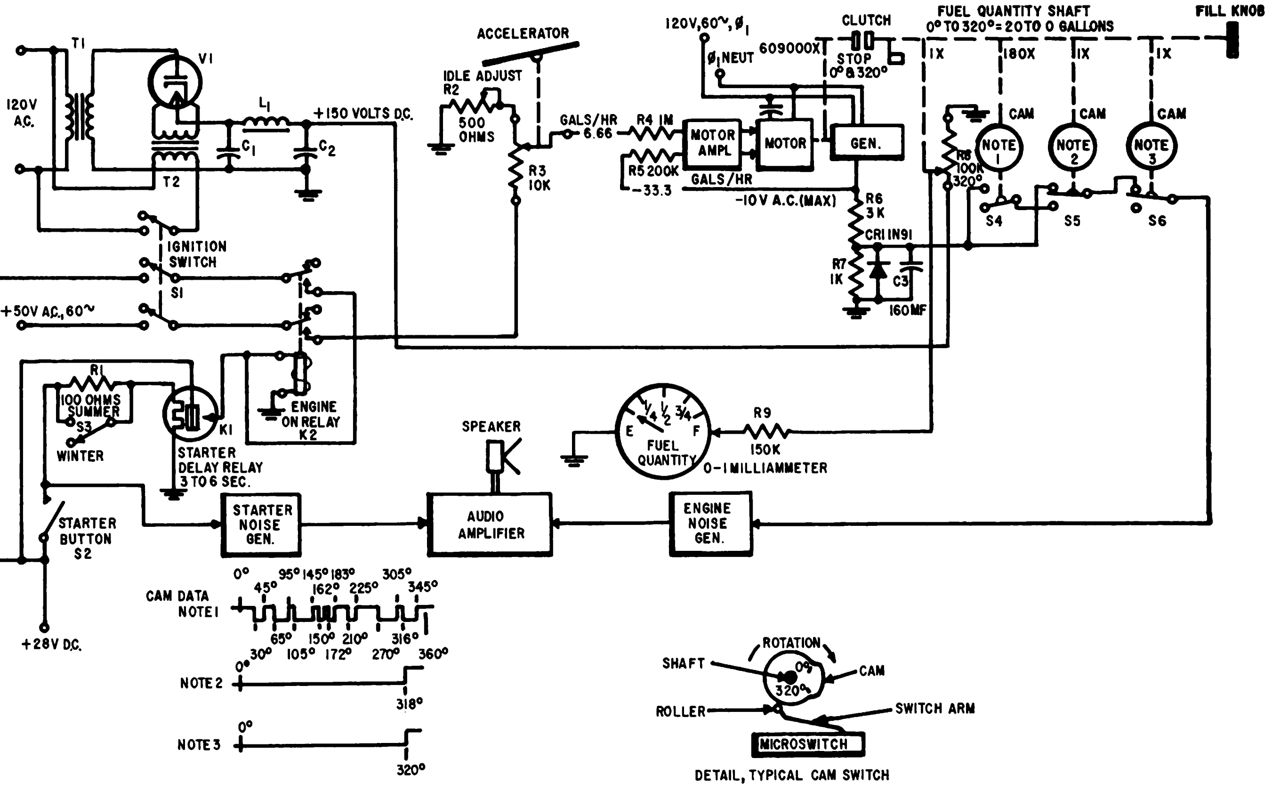


Figure 10-34.—A simple analog computer.

nition switch, whereupon the starter button ay be released and K2 will remain energized ntil such time as the ignition switch is opened break the holding circuit.

Switch S3 is shown in the winter position, hich means that the 100-ohm resistor, R1, is series with the thermal element of the arter-delay relay and hence it takes longer an normal for the contacts of this relay to ose and activate the engine-on relay. With witch S3 closed, R1 is shorted and the start- g time is reduced to simulate the summer ndition.

When both the ignition switch and the engine- n relay are closed, a 60-cycle voltage, labeled 0 volts a.c., is coupled to the bottom of the 0K potentiometer, R3. The plus sign is used erely to indicate that this voltage is 180° out phase with the generator feedback voltage entified in the figure as -10 volts a.c. (maxi- um). The wiper arm of R3 is mechanically oupled to the automobile accelerator, and hence the amplitude of the signal fed through R4 to the motor amplifier depends directly upon the amount the accelerator is depressed.

The gain of the motor amplifier is such that with a 50-volt signal applied to R4 (accelerator fully depressed) the motor develops 3,000 rpm. The motor, in turn, drives the horizontal portion of the shaft through a gearbox. The labelings adjacent to the vertical dashed lines connected to the horizontal shaft (such as 608000X, 180X, and 1X) indicate the speed of the vertical components with respect to the horizontal portion. Thus, with the accelerator held fully depressed, so that the motor is rotating at 3,000 rpm, the horizontal portion of the shaft will turn through 320° in 3 hours time. Since the winding of potentiometer R8 covers 320°, at the end of 3 hours of full speed operation the wiper arm will be at the top (ground) end, the voltage applied to the fuel quantity meter will be zero, and the instrument will indicate E (empty). If it is assumed that the full fuel tank holds 20 gallons and that this quantity will operate the engine for 3 hours at top speed, the maximum rate of fuel consumption will be 6.66 gallons per hour.

Minimum or idling speed occurs when all pressure on the accelerator is released and the wiper arm of R3 is, therefore, at the top of the potentiometer. Under this condition the only voltage applied to R4 is that existing across the screwdriver-adjusted idle adjust rheostat, R2. The positioning of this rheostat, therefore, simulates the idling adjustment of a conventional carburetor.

In the example under discussion (fig. 10-34), it is assumed that fuel consumption is approximately a linear function of accelerator position; that is, the rate of fuel consumption at full throttle is approximately twice that at half throttle, etc., and the voltage fed from R3 to R4 varies in this manner. However, the speed of conventional electric motors is not a linear function of voltage. For this reason the motor drives a generator, which feeds back to the motor amplifier a voltage opposite in phase to that supplied by the driving signal. The amplitude of this feedback voltage depends upon the speed of the generator (hence motor) rotation. At maximum speed (3,000 rpm), the generator output is about 10 volts. This occurs when the a-c potential at the wiper arm of R3 is 50 volts. If the accelerator is now retarded until the voltage at the wiper arm of R3 is 1/5 of its maximum value, or 10 volts, the motor speed will be reduced from 3,000 to 600 rpm and the negative phase output of the generator is reduced to 2 volts. With the accelerator held at the 10-volt position, any tendency of the motor to rotate at a speed greater than 600 rpm would result in an increased negative phase voltage from the generator and hence a reduction in the net input at the motor amplifier, which would bring the motor speed back to its correct value. Similarly, any tendency to underspeed would cause a reduction in the generator feedback and an increase in the net motor amplifier input which would again restore the rpm to its correct value.

In figure 10-34, the lead between the wiper arm of the accelerator potentiometer, R3, and the motor amplifier input resistor, R4, bears the label "6.66 GALS/HR" (gallons per hour). This label is known as a scaling number and, in all cases where such a number appears, it represents the magnitude of the given quantity or rate when and if the signal so labeled has a value of 50 volts (rms). Therefore, the label "-33.3 GALS/HR" appearing on the lead connecting the generator to R5 indicates what the effect of this voltage would be if it ever reached a value of 50 volts. However, as seen, the maximum value the feedback can have is 10 volts. This voltage is applied through the 200K resistor, R5, to the motor amplifier, while the signal voltage is applied through the 1-megohm resistor, R4. Ten volts acting through 200K is just as effective as 50 volts acting through 1 megohm. Thus, if the feedback voltage were increased to 50 volts, it would represent 5 x 6.66 or 33.3 gallons per hour. In actual practice the value of R5 is adjusted so that it is slightly greater than 1/5 the value of R4; hence, at any given speed there is a small net positive phase voltage at the input to the motor amplifier. The gain of the motor amplifier is high so that the difference between the signal and feedback voltages is amplified sufficiently to drive the motor at the desired speed.

From the foregoing discussion it is evident that the position of the shaft shown in figure 10-34, after any given lapse of time, depends upon what positions the accelerator pedal assumed during previous times and how long it was held at these various positions. For example: if, after starting, the car idled for 1/4 of an hour at the rate of 1/2 gallon per hour, then was driven steadily along a country road for 1 hour at the rate of 1 gallon per hour, and finally attained a uniform speed along a dual highway for 1/2 hour at 2 gallons per hour, the total fuel consumed would be 1/4 x 1/2 + 1 x 1 + 1/2 x 2 or 2.125 gallons. Setting up the proportion,

$$\frac{\text{degrees rotated}}{320} = \frac{2.125}{20}$$

shows that the shaft has rotated 34°. Applying Ohm's law to the circuitry consisting of the 150-volt d-c supply, R8, R9, and the meter will show that after 34° of shaft rotation (8,937.5 ohms between the wiper arm of R8 and ground), the meter current will be 0.89375 ma, which represents a fuel quantity of 17.875 gallons or a loss of 2.125 gallons as specified. It is evident that the fuel quantity shaft obtains the total of all of the individual rates of fuel consumption multiplied by the time that each rate is in effect. In other words, total fuel consumed = (rate_1 x time_1) + (rate_2 x time_2) + (rate_3 x time_3), etc. Hence, this part of the device is an example of an integrator, as explained in an earlier part of this chapter.

A portion of the generator output is taken off across R7 (fig. 10-34), rectified and filtered, and used as a control voltage for the engine noise generator. This control voltage is taken from the feedback generator rather than from the accelerator potentiometer for a very definite reason. In an actual automobiile, if the accelerator is suddenly thrust down, there is a short time lag before the engine reaches the new, higher rpm and increased noise output. In the simulation, due to the inertia of the motor-generator set and shaft, there is a similar lag in motor speed when the accelerator potentiometer is suddenly pushed down, and hence a corresponding lag in the increase of generator output, which enhances the realism of the simulation.

The rectified engine noise control voltage at R7 must pass through a series of cam-operated switches before reaching the engine noise generator. Mechanical details of the operation of a typical switch of this kind are illustrated in figure 10-34. When the rotation of the shaft brings the raised portion of the cam opposite the roller, the switch arm is pressed downward. Notes 1, 2, and 3 (fig. 10-34) show developed (flattened) contours of the outer surfaces of the cams which operate S4, S5, and S6, respectively. Thus, on the developed contours, the raised portions are equivalent to positions which push the switch arm downward.

When the tank is full of gas, the shaft is at 0° position and all three cam switches are in the positions shown. As the engine operates, the noise control signal bypasses S4 until the shaft reaches 318°, which is equivalent to an almost empty tank. At this time the arm of S5 is pressed downward, contacting the engine noise control voltage through S4. The cam which operates S4 is driven 180 times as fast as the shaft, and therefore note 1 shows that the arm of this switch is bouncing up and down in a random fashion, the cam completing a full revolution while the shaft is rotating through its final 2°. As a result, the engine noise will be cutting on and off to simulate the characteristic spluttering just before running out of fuel. Finally, when the tank is completely empty and the shaft is at 320°, cam switch S6 opens, cutting off all engine noise. At that time, the wiper arm of R8 will be at ground potential and the fuel quantity will, therefore, read E (empty). The mechanical stop at 320° prevents further rotation of the shaft and the motor simply turns against the slip clutch without any visible result. Turning off the ignition switch S1 then deactivates the entire computer.

ANALOG COMPUTER COMPONENTS

Some of the general characteristics of analog computer components are summarized in the following pages. Although details peculiar to certain manufacturers' products are not included, the essential factors affecting accuracy and reliability are discussed, since these are the items of principal interest for the TD who is responsible for making replacements or for evaluating operational equipment.

GENERATORS

A-C Generators

To develop an a-c voltage of line frequency having an amplitude proportional to the velocity of a shaft, a drag-cup induction generator (tachometer) can be employed (fig. 10-35). (This is the source of the generator feedback voltage used to stabilize the operation of the analog computer servo discussed earlier in this chapter.) The induction generator contains two windings which are physically displaced 90° from each other. One is energized from the line, while the other acts as the secondary of a transformer whose coupling is proportional to speed. Flux from the primary winding generates eddy currents in the cylindrical cup located in the airgap. There is a time phase difference between the eddy current flux and the flux from the primary winding. Therefore, when the cup is rotated at a constant velocity, a space phase shift of the generated flux results, proportional to velocity. Any eddy current flux that is not parallel to the primary flux induces a voltage in the secondary winding since this winding is physically 90° from the primary.

D-C Generators

D-c generators used as tachometers in computers are of the permanent magnet type in which Alnico magnet materials replace the field winding. These generators have good linearity and low ripple characteristics. To prevent voltage variation with brush wear, a hinged type brush is often used to maintain a fixed brush axis.

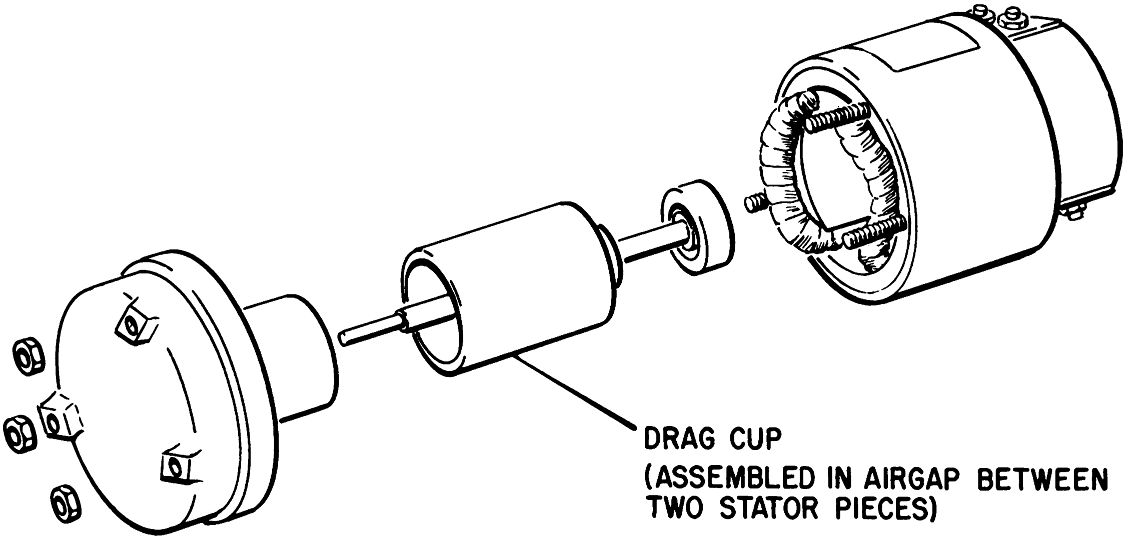


Figure 10-35.—Exploded drawing of drag-up generator.

TRANSDUCERS

The operation of synchros and differential synchros is described in detail in Basic Elec-ricity, NavPers 10086-A. Resolvers are dis-cussed in this chapter in the section on mathe-matical operations with computers. Other basic types of transducers are considered in the present discussion, which begins with informa-ion on variable autotransformers.

Variable Autotransformers

Variable autotransformers are commonly substituted for linear potentiometers to obtain better load regulation. Their operation is iden-ical with that of a transformer having a large number of secondary taps; input power must only supply the excitation current and output load, and so very little power goes into heat. The IR drop in the secondary windings is ex-remely low because relatively large copper wire is used for the windings. This makes it ossible to draw considerable power from the econdary without materially reducing its volt-ge—a feature useful in cascaded circuits where he load regulation of a potentiometer materially ffects its accuracy. A carbon brush must be sed to avoid a dead short between turns; other-wise, overheating and appreciable phase shift will occur. The use of a carbon brush also in-reases the autotransformer's effectiveness. This is true because of the following reasons:

1. A constant contact pressure can be maintained.
2. The contact area of the brush is such that it always contacts at least two coil windings.

Thus, an almost stepless output is provided. The phase shift and quadrature obtained are quite low, although there are generally some harmonics in the output.

E-Magnet Type

Another type of unit for similar use consists of an E-shaped member having one primary and two secondary windings coupled by a keeper which normally causes equal flux in the two opposed output windings. (See fig. 10-36.) As it is moved from the null position, the balance is destroyed, causing a net voltage proportional to excitation and keeper motion to be induced. Straight-line or rotary motion of the keeper depends on the mechanical design. There is usually a considerable amount of residual voltage and phase shift variation with this type of unit. However, where only a limited travel is required, it is applicable to many uses.

POTENTIOMETERS

Wire-wound potentiometers are perhaps the most common type of transducer, because of

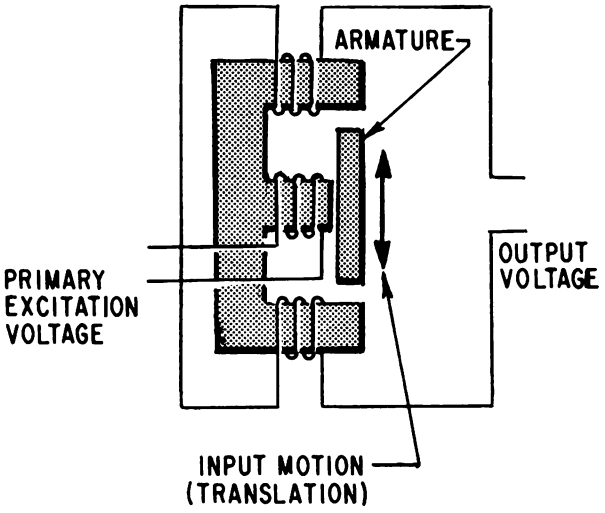


Figure 10-36.—E-shaped magnetic transducer.

their relatively low cost and freedom from residual noise. Their resolution is limited by the size and number of wire turns obtainable within the limits of angular travel. There is also a practical limit to the minimum resistance between the end terminals and the wiper at the maximum rotation position. This is known as end resistance and generally equals 0.025 percent to 0.1 percent of the total resistance, depending on the type of potentiometer used.

The linearity of a potentiometer is usually defined in terms of the ratio of maximum error at any point to the total travel expressed in voltage, resistance, or degrees. If the unit is adjusted so that there is no error at the winding extremities, the accuracy is defined as zero-based linearity. When the potentiometer must develop a certain function over a definite angle, accuracy may be defined by the linearity over this angle, with the unit phased to produce no error at the starting point. If the application so requires, linearity may also be expressed as the ratio of maximum error at any point to the voltage, resistance, or degrees corresponding to that point. However, this would allow no tolerance near the zero position, so the accuracy is more precisely expressed as a shaft error plus a percentage of wiper position.

Although there is no appreciable amount of residual static noise in a wire-wound potentiometer, there may often be a dynamic noise generated by the wiper contact moving over the wire. This is a primary function of contact pressure but is also dependent upon load current and impedance. The total resistance of a potentiometer usually has very little effect on system accuracy, and hence is subject to greater tolerance limits than many other computer components.

Precision potentiometers which contain a special form of carbon element that provides infinite resolution are available. The element has the disadvantage, however, of being adversely affected by humidity and temperature changes. These potentiometers should not be confused with ordinary, nonprecision units used as volume controls in many types of radio equipment.

When permitted in the application, the use of multiple-turn potentiometers or helipots (fig. 10-37) is generally desirable from the standpoint of resolution and accuracy compared to that obtainable in a single-turn potentiometer. For example, the total length of a resistance element may be at least eight times that of a single-turn potentiometer of equivalent diameter. However, a porportional increase in resolution is not necessarily obtained with the same overall resistance, unless a higher conductivity alloy is used. The effect of mechanical inaccuracy is greatly reduced in multiple-turn units if errors are referred to the same scale factor as used in single-turn potentiometers.

Potentiometer type transducers are more flexible than the inductive type in that nonlinear functions may be incorporated by one of several methods, which fall into four categories:

1. Shaped winding.
2. Variable-spaced winding.
3. The use of external variables.
4. Nonlinear wiper motion.

Shaped Winding

If the resistance wire is wound on a flat card whose width varies in poroportion to the derivative of the function desired and with minimum spacing between adjacent wires, the wiper output will follow the function curve. This occurs because successive turns contain different lengths of wire, and the resistance per turn changes accordingly. Therefore, the voltage drop varies from turn to turn, although the mechanical spacing is constant over the entire range. The electrical resolution, then, is merely a function of card width variation. Because of practical limitations in card width, there is a limit to the maximum slope of the curve which is to be

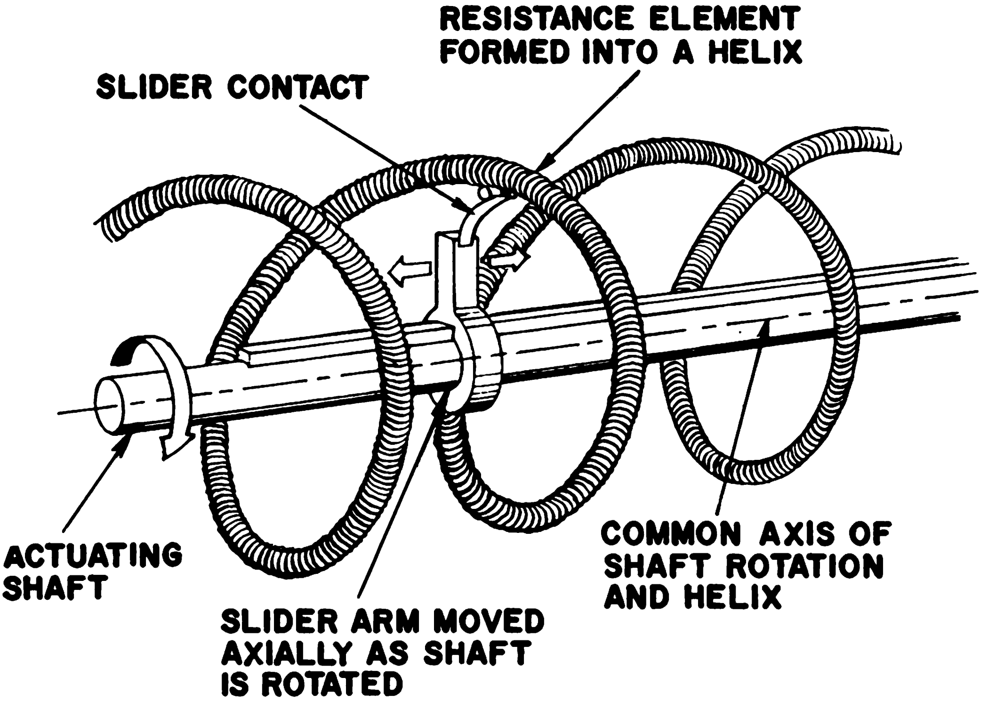

RESISTANCE ELEMENT FORMED INTO A HELIX
SLIDER CONTACT
ACTUATING SHAFT
COMMON AXIS OF SHAFT ROTATION AND HELIX
SLIDER ARM MOVED AXIALLY AS SHAFT IS ROTATED

Figure 10-37.—Multiple-turn precision potentiometer.

reproduced. This can be increased by changing wire size at various points as indicated in the typical card shown in figure 10-38. Although the card width in this case has sharp discontinuities, the resistance per turn follows a smooth variation resulting in an integrated output which is also a smooth curve.

Variable-Spaced Winding

Another method of obtaining nonlinear functions employs a card of constant width and varied spacing between turns. Wires are wound very close together where the slope of the function is a maximum. The maximum space between individual turns is limited by the size of the wiper, which must always touch the resistance wire. It, therefore, may be necessary to change wire sizes at regular intervals in order to extend the slope range of the function. It is generally difficult to attain the same rate of change with this method as with a shaped card without a considerable sacrifice in resolution. However, the spaced winding method may be applied to multiple-turn units, which offsets some of its limitations.

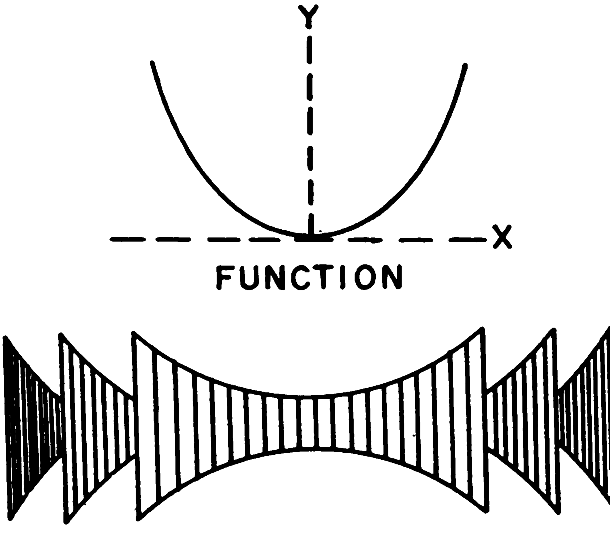


Figure 10-38.—Shaped-card potentiometer.

xternal Variables

A third method of obtaining a desired output nction employs a linear winding tapped at arious points, with fixed resistors bridging the ps. It is thus possible to reduce the effective esistance of certain sections of the winding, produce a series of straight-line approximaons to the desired output function. If a sufcient number of taps are used, the resulting urve will lie within the allowable tolerance and as shown in figure 10-39. This method may e applied to both single-and multiple-turn units nd avoids some of the winding complications herent in the methods previously described.

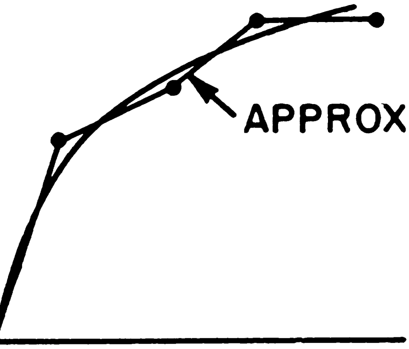


Figure 10-39.—Approximation of a curve through the use of external resistance.

A similar method is to connect each fixed tap of a linear potentiometer to a specific voltage. If the voltages applied to the taps are preselected to correspond with the specific output function, the potentiometer wiper output will again be a series of straight-line approximations to the desired function. (See fig. 10-39.).

Nonlinear Wiper Motion

Linear potentiometer windings may be used to develop nonlinear functions if the motion of the wiper is made to follow a similar function. One such type of winding employs a wire which acts as a wiper arm and is attached to the circumference of a drum forming a curve which corresponds to the desired output shape (fig. 10-40). This wiper contacts a linear resistance element lying parallel and adjacent to the drum which is driven by the input. As the drum rotates, contact is made between the wiper and resistance element in accordance with the position of the contact wire relative to angular position of the drum.

RELAYS

Relays used for switching functions in computer systems may have either a-c or d-c coils with contacts of sufficient size and pressure to handle the required load adequately. D-c relays are generally used whenever a suitable power source is available, because of their greater efficiency, faster action, and smaller size. In the plate circuit of a vaccum tube, the coil is generally wound with a large number of turns in

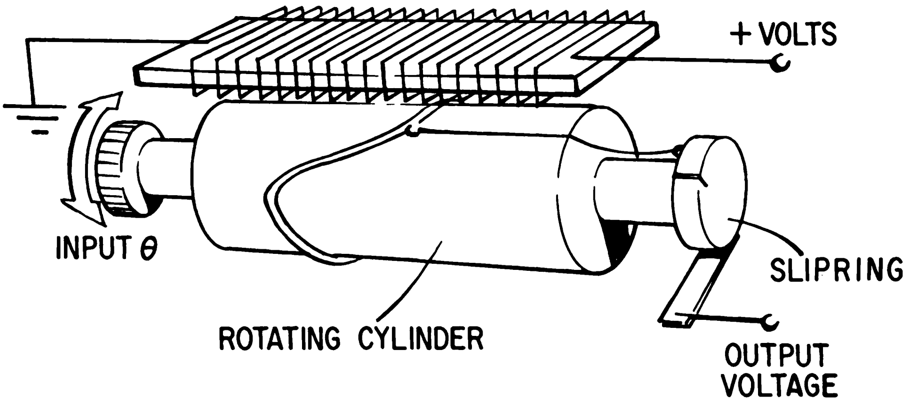


Figure 10-40.—Nonlinear function.

order to provide the best impedance matching and sensitivity. Relays which have critical control applications are generally constructed with a relatively large airgap so that the ratio of release current to operate current is high.

By adding a permanent magnet in the magnet circuit, the relay will respond to current of only one polarity. A differentially polarized relay employs an E-shaped circuit with a permanent magnet in the center leg, and a coil wound on each arm, with the armature pivoted about the center. Contacts are located at each end of the armature, one being actuated by coil current of one polarity and the other by the reverse polarity (fig. 10-41).

GYROS

The principles of the gyroscope are discussed in Chapter 4, "Instrument Flight," in TD 3 & 2, NavPers 10376-A. The gyroscopic properties of stability and precession are utilized in the construction of certain aircraft instruments, stability and precession are being utilized in the directional gyro and gyro horizon, while precession is utilized in the turn needle. In these applications, a mechanical linkage is employed to give a visual indication on the pilot's instrument panel.

In computer applications, it may become necessary to measure rates and position with respect to inertial space. This can be accomplished by making use of the properties of the gyroscope; but instead of employing a mech ical linkage to give a visual indication, the li age drives an inductive or resistive pickof give a voltage output. This output may then employed to drive a servomechanism.

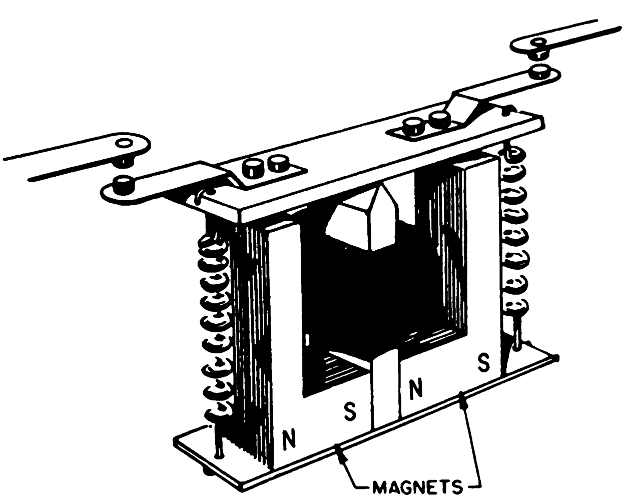


Figure 10-41.—Differential relay.

Gyros which operate on the principle of p cession are sometimes called rate gyros, si the magnitude of the output depends upon rate of rotation about the sensitive axis. accuracy of this type of gyro is affected variations in wheel speed, changes which aff the characteristics of the spring against wh the rotor precesses, bearing friction, and pick errors.

Gyroscopes operating on the principle stability may be called position gyros becau the rotor axis maintains a fixed attitude af being alined with some vector direction fr which indications of deviations are desired. a position gyro, variations in wheel speed aff sensitivity but not accuracy. Friction and i perfect balancing of the rotor also induce err and result in drift of the gyro. This makes necessary to reset the gyro periodically to r establish orientation in the original directi

COUNTING CIRCUITS

Counting circuits are defined as those c cuits which receive input pulses represent units to be counted and produce output voltag proportional to the applied pulse rates. The in waveforms must be uniform in amplitude and time duration if accurate counting is to resu and for this reason, counters are usually pr ceded by shaping and limiting circuits to insu the required uniformity.

Frequent application of the counter is made frequency dividing circuits. These contain bloc ing oscillators or multivibrators as the fi stages, which are controlled by counting circu and develop output waves at submultiple fr quencies of the input signals.

Typical counter circuits are simple combin tions of diodes, resistors, and capacitors. Th are classified as positive and negative, dependi on the polarity of the pulse they are designed accept. In frequency dividers, the counting dioc develop output voltages by the process cal step-by-step counting.

A detailed description of counting circu is contained in Basic Electronics, NavPe 10087-A.

CHAPTER 11

DIGITAL COMPUTERS

Automatic digital computers are becoming a common part of operational weapons systems. With many new ships, aircraft, and trainers, echnicians are faced with a collection of elecronic equipment which will have a digital computer as an integral part of the system. To understand anything about the operation of hese sophisticated systems, it is necessary o have some degree of acquaintance with digital computers and their terminology. Basic Electronics, NavPers 10087-A, chapter 19, gives an introduction to digital computers and the binary number system.

Airborne applications of digital computers are already operational. The CP-209 Computing Subsystem in the AN/ASB-7 Bomb Directing Set is a digital incremental computer. It automatically performs the required computations to provide navigational information, automatic or aided tracking, and automatic bomb release.

Training applications of digital computers are also in use. Trainers using operational data of weapons systems use digital computers o provide continuous reports of aircraft posiion, velocity, and attitude contained in automatic navigation systems. Navigational information required in the operation of the FBM rainer employes digital computers to store he complex data.

BASIC PRINCIPLES

The unfortunate connotation usually ascribed to the word "computer" sometimes raises the image of a complicated thought process being accomplished by some sort of giant "brain." Contrary to popular belief, computers cannot think. In general, they can only add, subtract, multiply, and divide. Their value is in the speed at which they operate. For example, one digital computer, which has been used in a military operation, can multiply six-digit numbers at speeds of 60,000 multiplications per second.

In contrast to analog computers, digital computers use discrete values to represent the digits 1 and 0, and the computations are performed by simple electronic switches and circuits. A fundamental difference between the two types is that the analog computer is continuously presenting a solution to the problem, while the digital computer performs each computation separately. In other words, when one of the factors in a problem changes, the solution presented by the analog computer changes continuously as the inputs change. In a digital computer, the entire computation must be performed again after each increment of change in the input.

An automatic digital computer does more than a desk calculator in that the computer can perform long sequences of operations without a human operator. The computer can even make decisions which may affect its future operations. However, no problem can be solved without someone first specifying every detail of the operation. The sequence of instructions which prescribes the problem solution is called the program.

Most of the computers used in naval equipments are part of control systems where time is a factor in the problem. The computer receives information from radar and other sources, and makes decisions, which are presented at the output to control some specific operation, such as an airborne interception.

An automatic digital computer generally consists of five major units: input, control, memory, arithmetic, and output. A simple block diagram appears in figure 11-1.

INPUT UNIT

For a computer to perform a specified series of operations, it must be fed both the instructions

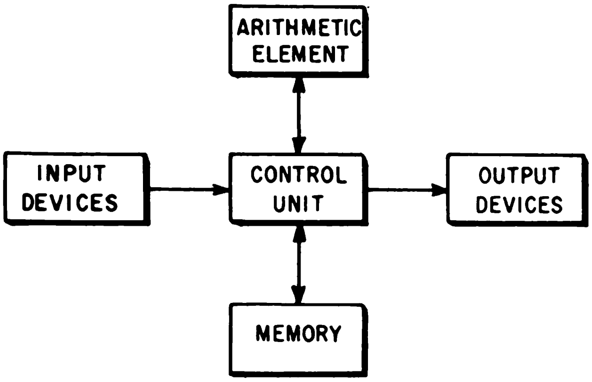


Figure 11-1.—Digital computer elements block diagram.

and the data to be used in the computations. Many different devices are used to properly present the information to the computer—for example, modified electric typewriters, punched card and punched tape readers, magnetic tape readers, and manual input components such as pushbuttons or toggle switches. In most applications, the most common input device is the analog-to-digital converter which changes the proportional voltage and current analogs into the digital form required by the numbering system used in digital computers.

CONTROL AND ARITHMETIC UNITS

The control unit in a digital computer interprets the instructions of the program and controls the actions of all other sections of the computer. It prescribes the exact sequence of events for all operations.

All of the mathematical operations are performed in the arithmetic unit of the computer. Addition, subtraction, multiplication, and division are performed when specified in the program, under the direction of the control unit. Results of these operations can then be put in the memory for future use.

MEMORY UNIT

The memory or storage section of the computer is used to store the information which is used during the computational process. It stores both the program instructions and the data used in the computation. The memory can be used to hold both intermediate and final results as the computer goes through the program. Common memory devices include: magnetic cores, magnetic drums, magnetic tapes, ultrasonic delay lines, and flip-flops.

Figure 11-2 shows a magnetic core memory. Each core can be magnetically saturated to either the 1 or the 0 polarity. Therefore, each core can hold just one bit of data at a given time.

Regardless of the type of memory employed, it is divided into a number of locations, each of which is identified by an address. When the control unit calls for an instruction from the program or a piece of information which is stored in the memory, it acquires the information by using the proper address to establish the path to the appropriate memory element and the data stored there. The normal construction of storage devices makes any address accessible. However, the length of time required to obtain the information is determined by the type of storage device.

The information stored at each address is referred to as a "word." Each word is represented by a number of pulses or signal voltage levels. The storage can be accomplished on tape, magnetic devices, or special circuits. A word can represent either a numerical quantity or a computer instruction, but only one word can be stored in any given address.

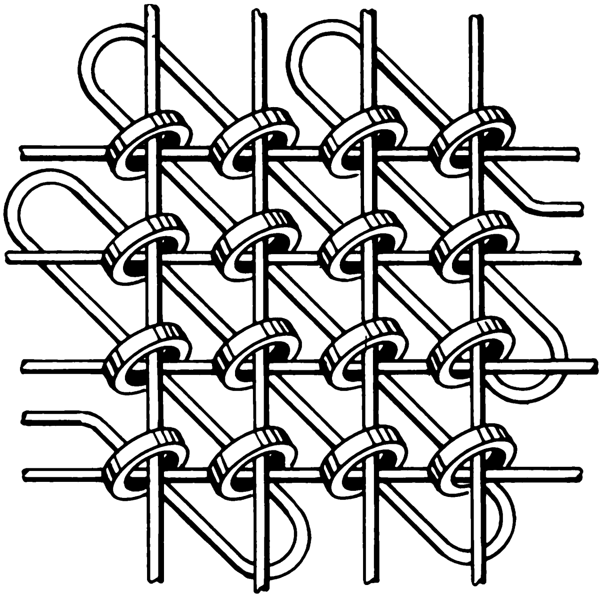


Figure 11-2.—Magnetic core memory cell.

OUTPUT UNIT

After the computer has performed the computations, there must be some method of communicating the results to the operator. The devices used to "readout" the results are similar to those used in the input: punched cards or tape, magnetic tape, and so forth. Specialized output units include audio or video displays and digital to analog converters.

Several special facilities are included in digital computers. When an operation is to be performed in an arithmetic unit, only one word at a time can be transferred from the memory unit. To perform an operation with two words, the first word must be stored momentarily while the second word is being transferred. For this function, the arithmetic unit has special memory cell called an accumulator.

The accumulator is one of a class of memory devices called registers. A register is simply a means of storing temporarily a certain amount of information. The methods of storage may be the same as those used in the memory, but the register can only store one word at a time. Other registers are used in the computer, such as the instruction register associated with the control unit which allows reference to the instruction being interpreted during the time control signals are being set up.

SEQUENCE OF OPERATIONS

Before a computer can do any problem solving, the steps for the solution must be written down in the form of a program and then translated into machine language (coded). The coded instructions in digital form are placed in the correct locations in the memory and the computer is ready to operate.

Assume that the computer starts in compliance with the program, with the control unit reading the instruction stored in the first storage location, address 01. The digits at this address might tell the computer to "take the number in storage location 12 and put it in the arithmetic unit." After following the instruction, the control unit cycles to the next step, address 02. The instruction at this address might be, "take the number at storage location 22, divide it by the number in the arithmetic unit, and leave the answer in the arithmetic unit." The next instruction, at address 03, might be to "take the number in the arithmetic unit (the result of the above division) and put it in storage location 36."

The final instruction in the sequence of operations would provide for the readout of the result.

NUMBER SYSTEMS

The familiar decimal number system is not suitable for high speed electronic computations. No electronic device has been developed which can reliably and economically represent all of the 10 digits. However, there are many devices which can be used to represent two states of nature: switches, relays, transistors, or tubes. Each of these can be operated in such a manner as to be clearly classified as "off" or "on." In other words, they are bistable devices. The numbering system which represents only two states is called the binary system.

Numbers written in the binary system use only the symbols 0 and 1, called bits, just as the ten symbols in the decimal system are called digits. The number of symbols used in any system is called the base or radix of the system. Thus, the decimal system has a radix of ten, and the radix of a binary system is two. Many different bases are used, such as 12 in the duodecimal system for counting by the dozen and relating inches to feet. The base is used in any number system to determine positional value of each digit. For example, in the decimal system, (where the base is ten) 6,346 actually means $(6 \times 10^3) + (3 \times 10^2) + (4 \times 10^1) + (6 \times 10^0)$. (Remember that any number raised to the 0 power is equal to 1.) Similarly, in the binary system, (where the base is two) 1011 actually means $(1 \times 2^3) + (0 \times 2^2) + (1 \times 2^1) + (1 \times 2^0)$, or 11 in the decimal system. The binary equivalents of the first 10 decimal numbers are:

Decimal		Binary
1	=	1
2	=	10
3	=	11
4	=	100
5	=	101
6	=	110
7	=	111
8	=	1000
9	=	1001
10	=	1010

The arithmetic manipulation of this system is discussed in Basic Electronics, NavPers 10087-A.

Words are memorized by the computer as binary numbers. A word is composed of a series (or train) of 1 and 0 signal voltage levels, or pulses. The number of bits (1 or 0 symbols) in the word is called the length of the word. The speed of a computer is denoted by the rate at which the pulses pass a given point, or equivalently by the pulse repetition frequency. The circuits which manipulate the pulse trains are called gates, logic circuits, or digital switching circuits.

All the pulses in a computer are normally synchronized with respect to each other by means of a clock pulse, which is driven by an oscillator whose frequency is an integral multiple of the speed of the computer.

Figure 11-3 shows a typical word and the waveform of its associated pulse train. In this case, the length of the word is seven bits. The corresponding clock pulse train is also shown. In this figure, a pulse represents a 1, and the lack of a pulse represents a 0 symbol.

SYMBOLIC LOGIC

The operations performed by a digital computer are based on a logical reasoning process. Since the rules for the equations and manipulations employed by the computer differ from the ordinary rules of arithmetic, understanding this subject requires some discussion of the basic concepts involved.

Probably you will recall, from your review of Basic Electronics, NavPers 10087-A, that the symbolic operations utilized in digital computers are based on the investigations of George Boole, and the resulting algebraic system is called Boolean algebra. It is similar to the algebra with which we are all familiar, but it follows different rules.

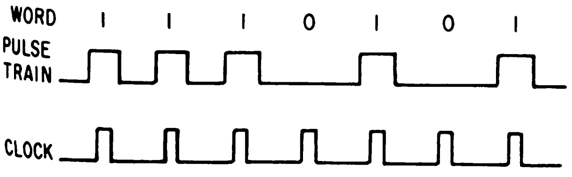


Figure 11-3.—Waveform of seven-bit word and its clock pulses.

To understand Boolean notation, the technician must ignore some of the things he has learned about the arithmetic use of the dot and plus connectives, as their use in logical operations is different from the arithmetic usage.

The equations which characterize Boolean algebra are given in table 11-1. Notice that some of the rules are quite different from those of ordinary algebra.

The three basic functions needed for representation of expressions such as those in table 11-1 are the AND function, the OR function, and the NOT function. The meanings of these are discussed in Basic Electronics, NavPers 10087-A.

Electronic circuits which are used in mechanizing the AND, OR, and NOT functions are described in the following paragraphs. Closely related to these are the INHIBITOR circuit and the EXCLUSIVE OR circuit, which are also discussed.

LOGIC CIRCUITS

Logic circuits are the hundreds of high speed electronic switching circuits of a digital computer that store information signals and perform logical operations on the information signals. In the first case, the pulse trains representing information are stored temporarily in circuits such as registers, which can be made up of multivibrators. In the second function, circuits such as the basic NOT, OR, and AND types perform logical operations. These circuits sense the input conditions and produce an output only if certain input conditions exist. This is one of the reasons for their names. They can also be generally classed as gate circuits.

A digital computer will generally contain a great many of these logic circuits, but the types of circuits contained will be limited to the smallest number that can perform the required functions. This improves maintainability. The circuits may use vacuum tubes, transistors, diodes, tunnel diodes, silicon rectifiers, or other elements such as magnetic cores. No attempt is made to cover all variations of all types of logic circuits. Coverage will be limited to a representative few of each type in order to present an idea of their nature and use. Also emphasis will be on circuits using semiconductors rather than vacuum tubes.

Table 11-1.—Equations of Boolean Algebra.

1. $A + A = A$
2. $A \cdot A = A$
3. $A + B = B + A$
4. $A \cdot B = B \cdot A$
5. $(A + B) + C = A + (B + C) = A + B + C$
6. $(A \cdot B) \cdot C = A \cdot (B \cdot C) = A \cdot B \cdot C$
7. $A \cdot (B + C) = A \cdot B + A \cdot C$
8. $A + A \cdot B = A$
9. $A + B \cdot C = (A + B) \cdot (A + C)$

$$\left.\begin{array}{l} 10.\ \overline{A \cdot B} = \overline{A} + \overline{B} \\ 11.\ \overline{A + B} = \overline{A} \cdot \overline{B} \end{array}\right\} \text{DeMorgan's Theorems}$$

12. $A + 1 = 1$
13. $A \cdot 1 = A$
14. $0 + A = A$
15. $0 \cdot A = 0$
16. $A + \overline{A} = 1$
17. $A \cdot \overline{A} = 0$
18. $A + \overline{A} \cdot B = A + B$
19. $A \cdot B + B \cdot C + C \cdot A = (A + B) \cdot (B + C) \cdot (C + A)$
20. $A \cdot \overline{B} + A \cdot C + B \cdot C = A \cdot \overline{B} + B \cdot C$
21. $\overline{\overline{A}} = A$

NOT FUNCTION

The NOT circuit, also known as an inverter circuit, is probably the simplest of all. It is nothing more than a normal gate amplifier stage that produces an inversion (negation) of the input signal and has unity gain. Figure 11-4 is such a vacuum tube circuit.

The triode V1 is biased beyond cutoff,and the positive input signal shown is applied. (The stage would be biased for heavy conduction if a negative signal were applied to the input.) The voltage divider (R1 and R2) in the grid circuit is for the purpose of limiting the circuit gain to unity. Note that the input-output table (truth table) shows that the circuit produces an output which is the opposite of the input. This is the negation function. The Boolean algebra expression is

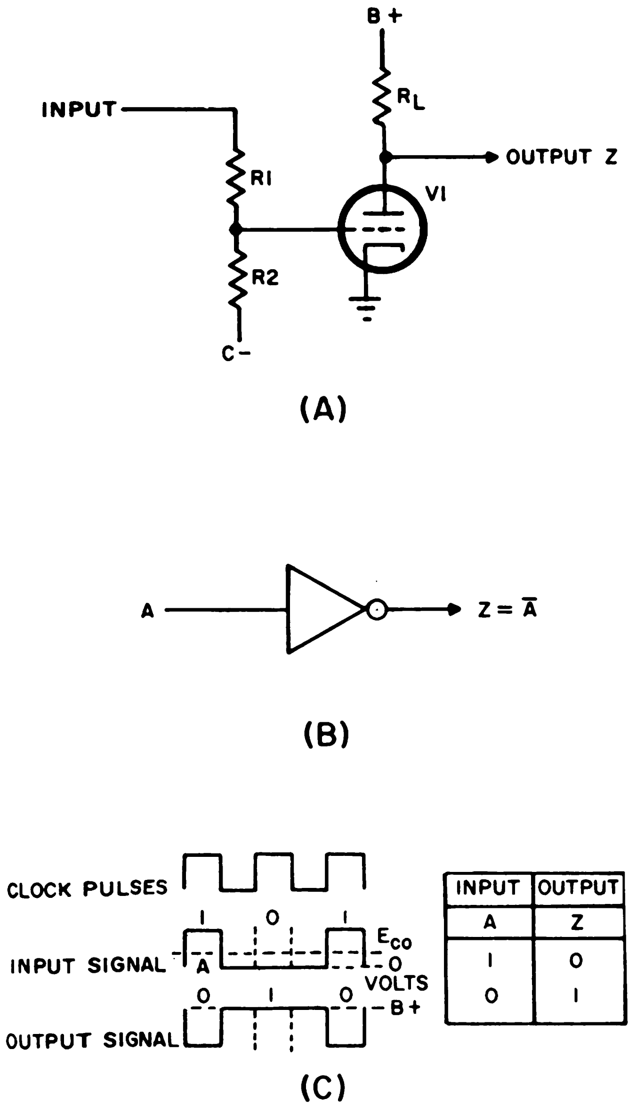
$$Z = \overline{A}$$

which is read

"Z equals A-NOT."

Transistor Circuit

Figure 11-5 is a NOT circuit employing a PNP transistor in a common emitter configuration. When no signal is applied, Q1 is biased to cutoff by the voltage divider, consisting of R2 and R3, which makes the base



INPUT	OUTPUT
A	Z
1	0
0	1

Figure 11-4.—(A) NOT circuit; (B) block diagram symbol; (C) waveforms and related truth table.

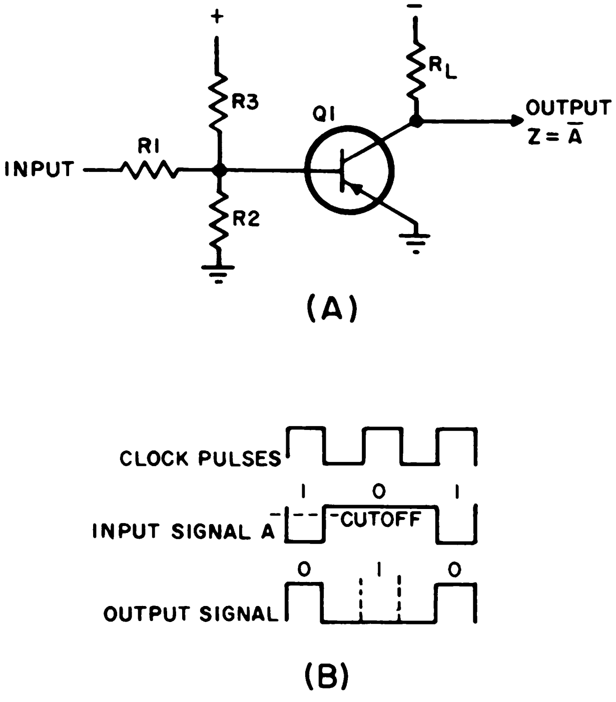


Figure 11-5.—(A) Transistor NOT circuit; (B) waveforms showing inversion between input and output.

positive with respect to the emitter. The input signal is divided by R1 and R2, making the circuit gain equal to unity. Note that the input signal must be negative to cause conduction and that the output developed across Q1 is the opposite of the input. The block diagram symbol, Boolean algebra expression, and truth table of figure 11-4 would also apply to figure 11-5.

Note that any device or circuit that inverts a signal between the input and output with unity gain meets the definition of a NOT circuit. One commonly used NOT circuit device is the transformer.

OR FUNCTION

An OR circuit is a logic circuit that has two or more inputs and produces an output if any or all inputs are applied. It is very similar to an audio mixer stage, since several inputs can be applied from different sources without interaction upon the sources; and any input signal produces an output signal.

Vacuum Tube Circuit

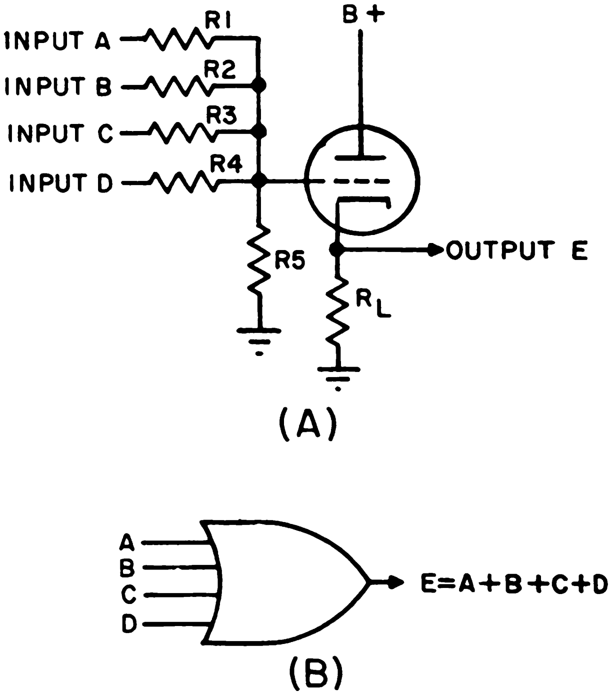
Figure 11-6 shows a vacuum tube OR circuit with four inputs, the block diagram symbol, and the truth table. In the truth table, a signal is represented by a 1, and the lack of a signal is represented by a 0.

Each input signal is applied to the grid through a resistance voltage divider to reduce the interaction between sources when more than one input is applied. Since the stage is a cathode-follower, the output is taken from the cathode without signal inversion. Positive or negative signal pulses (either of which could be designated to represent a 1 at the same time the other represents a 0) can be applied, with all input sources supplying like polarity signals for 1's or 0's.

It is assumed that each 1 pulse is of sufficient amplitude to cause heavy conduction if the signal is positive or to cause cutoff of the tube in case the 1's are represented by negative signals. Therefore, if two 1-signals are applied simulataneously, an output signal of standard amplitude is still obtained.

Diode Circuit

The simplest of all OR circuits is probably a diode circuit such as figure 11-7. Again, four inputs are shown; and it is assumed that



INPUTS				OUTPUT
A	B	C	D	E
0	0	0	0	0
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1
1	1	1	1	1

(C)

Figure 11-6. — (A) Vacuum tube OR circuit; (B) block diagram symbol; (C) truth table.

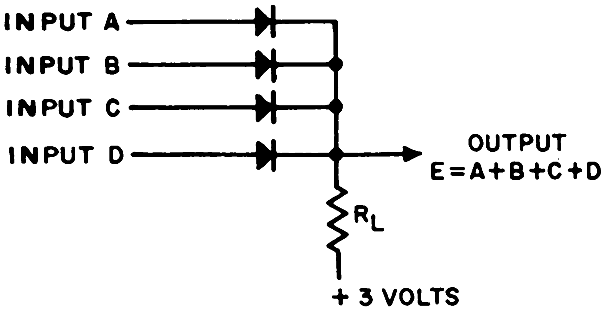


Figure 11-7.—Diode OR circuit.

the signals are positive with respect to ground. In that case, each diode will conduct heavily through R_L and the source circuit (not shown) when a positive pulse greater than about 3 volts occurs.

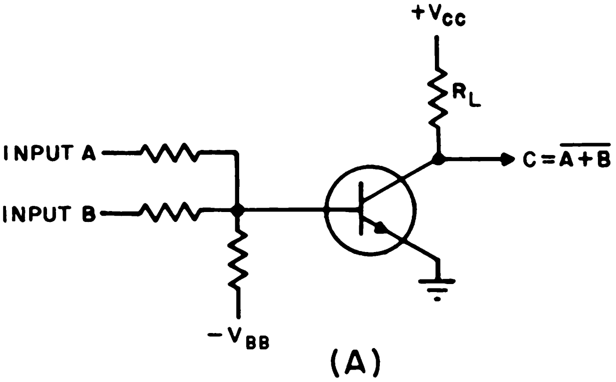
The output is taken from across R_L and is not inverted. The block diagram symbol and truth table of figure 11-6 are applicable to this circuit. The circuit, by reversing the diodes and the polarity of the 3-volt source, will function for bit pulses that are negative with respect to ground.

Transistor Circuit

Figure 11-8 shows a transistor type OR circuit that also includes the negation function of a NOT circuit. A circuit that performs both logic functions is sometimes called a NOR circuit.

With no input signal applied, the NPN transistor (fig. 11-8) is biased to cutoff by the negative bias applied between base and emitter. A positive input pulse causes saturation conduction of the transistor, producing a negative output pulse at the collector. The truth table shows the NOT and OR functions tabulated for various input conditions that may exist. Similar circuits could be arranged for negative input signals by biasing an NPN transistor to sturation conduction or by biasing a PNP transistor to cutoff.

AND FUNCTION



(A)

INPUTS		OUTPUT
A	B	C
1	0	0
1	1	0
0	1	0
0	0	1

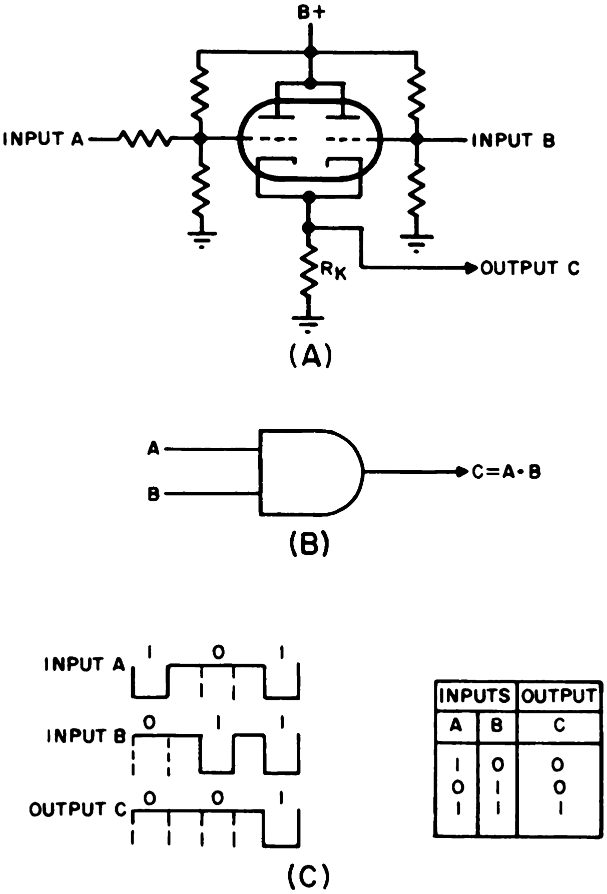
(B)

Figure 11-8.—(A) Transistor OR circuit; (B) truth table.

An AND circuit is very similar to the familiar coincidence circuit which has been used in other electronic equipment for many years. All input signals must be alike (representing either all 1's or all 0's) and occur at the same time to produce a useful output. Therefore, AND circuits find wide use in interpreting control instructions and performing logical operations upon signals in the arithmetic portion of the digital computer. Several circuit configurations are possible, using various circuit elements.

Vacuum Tube Circuit

Figure 11-9 is a vacuum tube AND circuit that uses a dual-triode. Assume that each negative-going portion of the input and output signals represents a binary 1 and that both sections of the tube conduct heavily during the binary 0's of the input signals. During the first binary 1 signal of input A, the conduction of the left-hand section is reduced. However, the right-hand section is still conducting heavily; and there is no noticeable output signal produced across R_K. During the first binary 1 signal of input B, a similar result is obtained because the left-hand section will be conducting heavily. But when inputs A and B both represent binary 1 signals, both sections of the tube are driven



INPUTS		OUTPUT
A	B	C
1	0	0
0	1	0
1	1	1

Figure 11-9.—(A) Vacuum tube AND circuit; (B) block diagram symbol; (C) waveforms and related truth table.

to cutoff; and a binary 1 is produced across R_K. The truth table summarizes the conditions for the three combinations of input signals. Note that this circuit functions as an AND circuit for negative signals only. It will not function as an AND circuit for positive signals, no matter what static bias conditions exist.

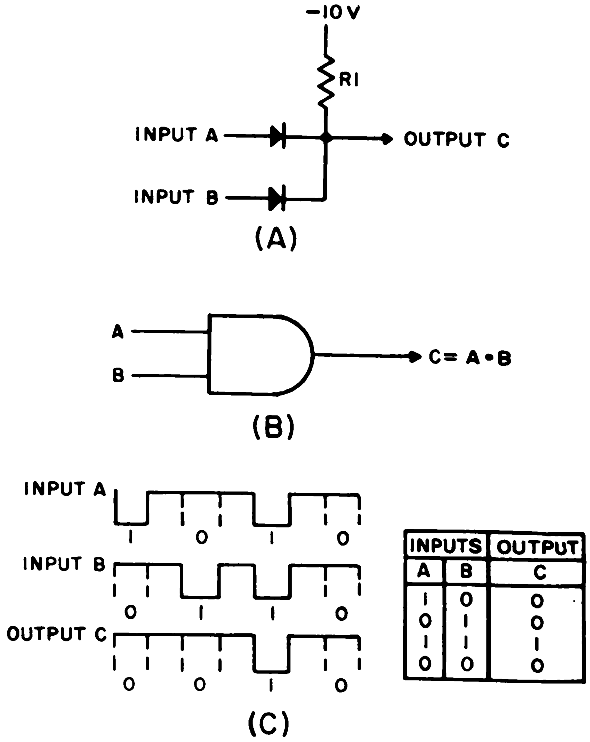
There are at least two other commonly used AND circuits that employ vacuum tubes. The circuit of figure 11-9 could be arranged to perform the dual functions of AND and NOT if the load resistor were placed in the plate circuit. A pentode tube having two grids that control the tube's conduction can function either as an AND circuit or as a combination AND and NOT circuit, depending on whether the output is taken from the cathode or plate circuit. Such a combination is sometimes called a NAND circuit.

Diode Circuit

The circuit of figure 11-10 uses two diodes to perform the AND function. Under static signal conditions, or with binary 0 input for both A and B, the diodes are conducting heavily through R1 and the resistances of the input circuits (not shown). The output level is therefore near zero volts. R1 is much larger than the input circuit resistance of the conduction path, and nearly all of the -10 volts is dropped across R1 because the diodes have very little forward resistance.

When input A is a 1 and input B is a 0, the diode of input A is cut off. However, there is no output, because the diode in input B is conducting and essentially shorcircuits diode A.

When inputs A and B both represent 1's, both diodes are cut off. The output terminals then goes negative about 10 volts. This is the third set of conditions shown in the truth able; with the signals and conditions shown, none of the other signal conditions will produce a useful output from the circuit.



INPUTS		OUTPUT
A	B	C
1	0	0
0	1	0
1	1	1
0	0	0

Figure 11-10.—(A) Diode AND circuit for negative signals; (B) block diagram symbol; (C) waveforms and related truth table.

By reversing the diodes and the -10 volts, an AND circuit can be produced that will handle and produce signals of exactly the opposite polarity. Also, in either case, the circuit is not limited to two input signals; three, four or five inputs are common in almost all logic circuits except the simple NOT circuits.

Transistor Circuits

Four transistor AND circuits, the first three of which include the NOT function, are shown in figure 11-11. These are not the only circuits possible; however, they are illustrative of the wide range of AND circuit configurations possible.

The AND circuit in figure 11-11 (A) uses two PNP transistors that are initially biased for saturation conduction by the negative-base to emitter voltage. If both bases are driven to cutoff at the same time by positive signals, both transistors stop conducting; the collector output signal thus goes in a negative direction, producing the AND NOT (NAND) function. Remember, this means an output pulse (negative, in this case) is produced only if both A AND B are NOT negative.

The two NPN transistors of figure 11-11 (B) are also statically biased for saturation conduction by the positive-base to emitter voltage. When two negative input signals are applied simultaneously, both transistors are driven to cutoff; the collector output thus increases in a positive direction. If only one base is driven negative at a particular time, the other transistor continues to conduct; this keeps the output terminal at practically ground potential. The circuit thus performs as an AND NOT circuit.

The circuit of figure 11-11 (C) is somewhat different. Statically, each transistor is cut off. During operation, all three must conduct together. If any transistor remains cut off, the others cannot conduct because the emitter-collector conduction paths of the three are in series. If all three transistors are driven into conduction by negative signals applied to the bases, there will be conduction; and the collector voltage at the output terminal will increase in a positive direction. The circuit thus performs as an AND NOT circuit.

Four PNP transistors are connected together at the collectors and emitters (fig. 11-11 (D)) to form an emitter-follower type circuit. However, there are four separate input terminals for the base signals. Initially, all four transistors are in saturation conduction and

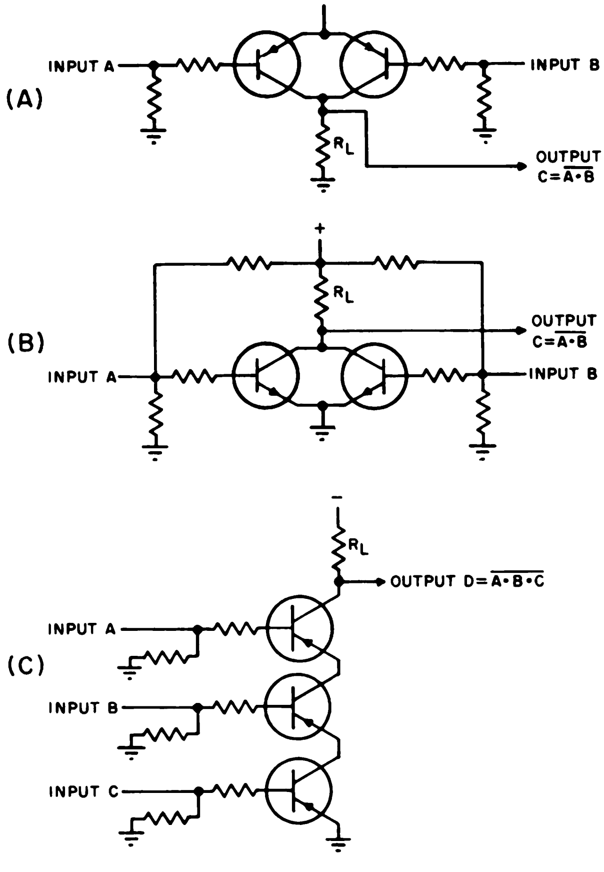

(A)
+
INPUT A
INPUT B
R_L
OUTPUT $C=\overline{A\cdot B}$
(B)
+
R_L
OUTPUT $C=\overline{A\cdot B}$
INPUT A
INPUT B
(C)
-
R_L
OUTPUT $D=\overline{A\cdot B\cdot C}$
INPUT A
INPUT B
INPUT C
(D)
-
INPUT A
INPUT B
INPUT C
INPUT D
OUTPUT $E=A\cdot B\cdot C\cdot D$
R_L

Figure 11-11.—Examples of transistor AND circuits.

early all of the collector voltage is dropped cross R_L. Again, all transistors must be cut ff together to reduce the voltage drop across $_L$. The application of four positive input sig-als to be bases will cut off each transistor, nd the output terminal voltage will go in a pos-tive direction. Note the lack of the NOT logic unction; that is, the circuit does not perform s an AND NOT circuit.

NHIBITOR CIRCUITS

The combination of an AND and a NOT cir-uit in which the NOT circuit is inserted be-ween one input terminal and the AND circuit s called an INHIBITOR circuit. Figure 11-12 A) shows the functional arrangement of the com-ination. Figure 11-12 (B) shows a more com-nonly used block diagram symbol, where the nhibit signal input to the block is through a alf circle. The NOT and AND circuits can take he forms of any circuits described previously; he only requirement for the NOT circuit is that t inverts its input signal.

The circuit in figure 11-12 (B) produces an utput under the following conditions only: One r more regular input signals are applied, but o input signal is applied to the inhibit terminal.

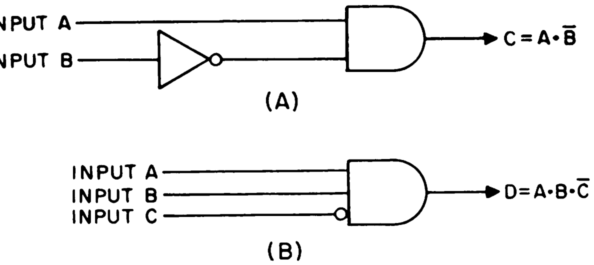


Figure 11-12.—INHIBITOR circuits. (A) Two inputs; (B) three inputs.

XCLUSIVE OR CIRCUIT

An EXCLUSIVE OR circuit is a combination f circuits which has two input signal terminals ut produces no output when two signals of like olarity are applied simultaneously. However, f only one input signal is applied, an output s produced.

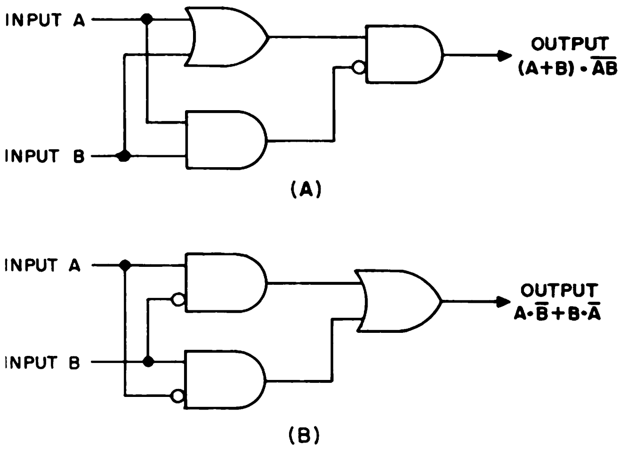

INPUT A
INPUT B
OUTPUT
$(A+B)\cdot\overline{AB}$
(A)
INPUT A
INPUT B
OUTPUT
$A\cdot\overline{B}+B\cdot\overline{A}$
(B)

Figure 11-13.—Two forms of EXCLUSIVE OR circuits.

Two combinations of circuits that can be sed to form the EXCLUSIVE OR circuit are hown in figure 11-13. For the circuit of figure 1-13 (A), input signal A will pass through the OR and INHIBITOR circuits to the output if no signal from the AND circuit reaches the inhibitor terminal. But if a signal is applied to input B, which operates the AND circuit, a signal reaches the inhibit terminal and prevents any output. In figure 11-13 (B), two simultaneous input signals will prevent an output from both of the INHIBITOR circuits, and the OR circuit will thus produce no output.

Signals A and B are signals that occur simultaneously and are alike for the conditions of no output. Because of this characteristic, the circuits can be used to compare two pulse trains and to produce an alarm signal output when the two trains are not always identical. In this manner, two corresponding circuit points of two identical computers can be constantly examined for errors.

PULSE RESHAPING CIRCUITS

Although reshaping circuits do not, strictly speaking, perform a logic function, they use circuits that are classed as logic circuits. Their function is the reshaping of pulse trains that may have deteriorated in shape and amplitude beyond further usability. As pulse trains pass through various circuits of a computer, the rise and fall times of the pulses usually increase; the amplitude may decrease; and the pulses are delayed in time.

The clock pulses, which are usually available at several points in the computer, are used with a reshaping circuit to restore the shapes of numerical or instructional information pulses within the computer.

If the information pulses to be reshaped occur at the same time as an available clock pulse, a simple AND circuit can be used to reshape the pulse. Figure 11-14 (A) shows clock pulses and deteriorated pulses applied simultaneously to terminals A and B, respectively, of an AND circuit. In a properly designed circuit, the output is produced only during the time interval t_1 to t_2. The rounded top of the output pulse can be clipped in a succeeding amplifier stage.

Instances will occur where the deteriorated pulses to be reshaped are no longer in time synchronization with the clock pulses. In these cases, the circuit shown in figure 11-14 (B) can be used to reshape the pulses.

The deteriorated pulses and clock pulses are applied to terminals A and B, respectively. The deteriorated pulses pass through the OR circuit and, together with the clock pulses, cause an output from the AND circuit during the portion of the time that they occur simultaneously.

If there were no regenerative (positive) feedback from the amplifier output, the output would be representative of only the overlap time of the deteriorated and clock pulses. However, the positive feedback and the clock pulse keep the AND circuit functioning, producing an input to the amplifier until the clock pulse ends. This produces an output pulse that is identical to the clock pulse. Note that this circuit allows a pulse that is not in exact time sequence with a clock pulse to be reshaped, but there must be some overlap in the duration of the two pulses.

ARITHMETIC CIRCUITS

An automatic digital computer is a vastly complicated machine with a great many electronic circuits. Although the number of circuits is high, the variety is small. That is, it consists of a large number of a few types of gate circuits. Many of the types found in the arithmetic unit were discussed in the preceding section as logic circuits. An additional type of logic circuit not previously discussed, the Eccles-Jordon multivibrator, known as a flip-flop (FF), is in wide use in the binary counters and the registers of the control and arithmetic units.

The following paragraphs discuss how the FF and other logic circuits are combined to form counters, registers, and adders; and how they perform the temporary storage, addition, subtraction, multiplication, and division functions of the arithmetic unit.

FLIP-FLOPS

In most cases, the registers in the arithmetic unit and the binary counters in the control unit

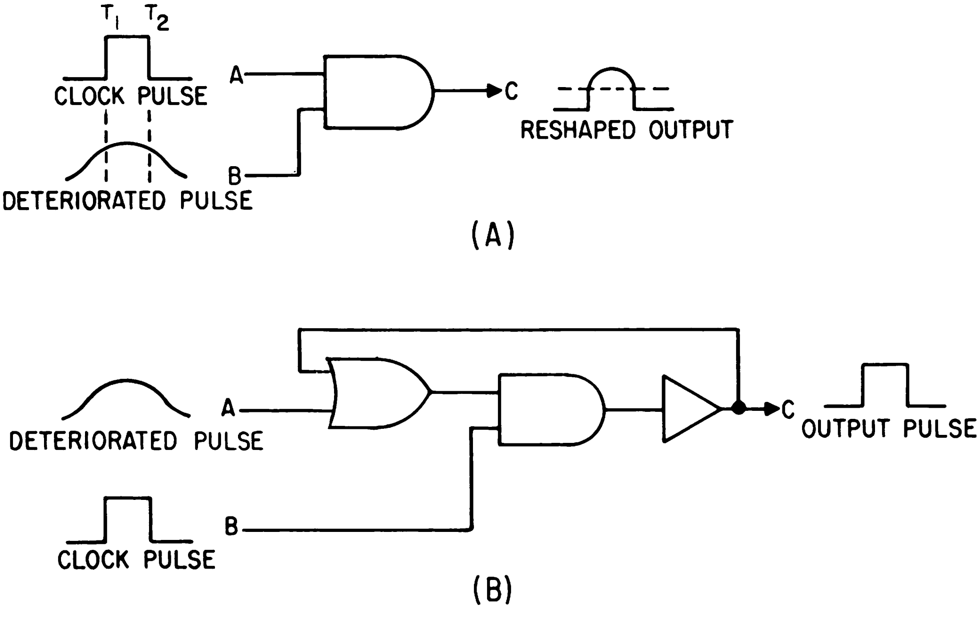


Figure 11-14.—Block diagram of pulse reshaping circuits.

are composed of FF's constructed with vacuum tubes or transistors. Where a register in the arithmetic unit uses an associated binary counter, the counter is also composed of FF's. The basic functions of a counter or register are to totalize the numbers of bits and to provide temporary storage for this information. Once a number of bits has been fed into the counter or register, the information is retained until the circuit is cleared by a reset (clear) signal or the power is removed from the circuit.

Figures 11-15 and 11-16 show two FF's, one composed of vacuum tubes and the other of transistors. Other devices that are capable of two states of operation (for example, tunnel diodes or magnetic core coils) can also be used in the construction of FF's. A block diagram symbol commonly used to represent the FF in computers is also shown in figure 11-15.

In the following discussion, it is assumed that the technician is familiar with the operation and general use of the FF circuit. (The

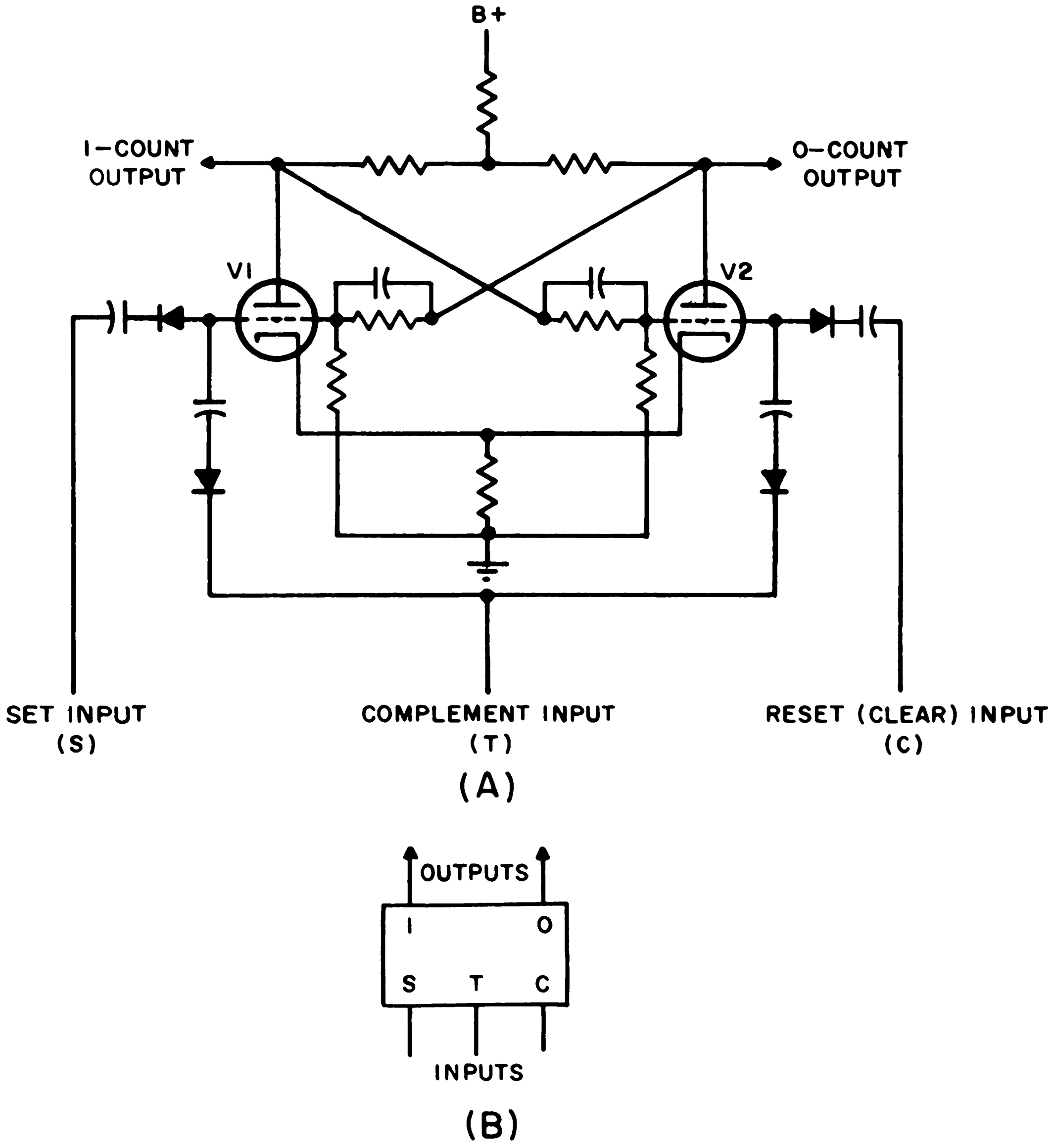


Figure 11-15.—(A) FF using vacuum tubes; (B) block diagram symbol.

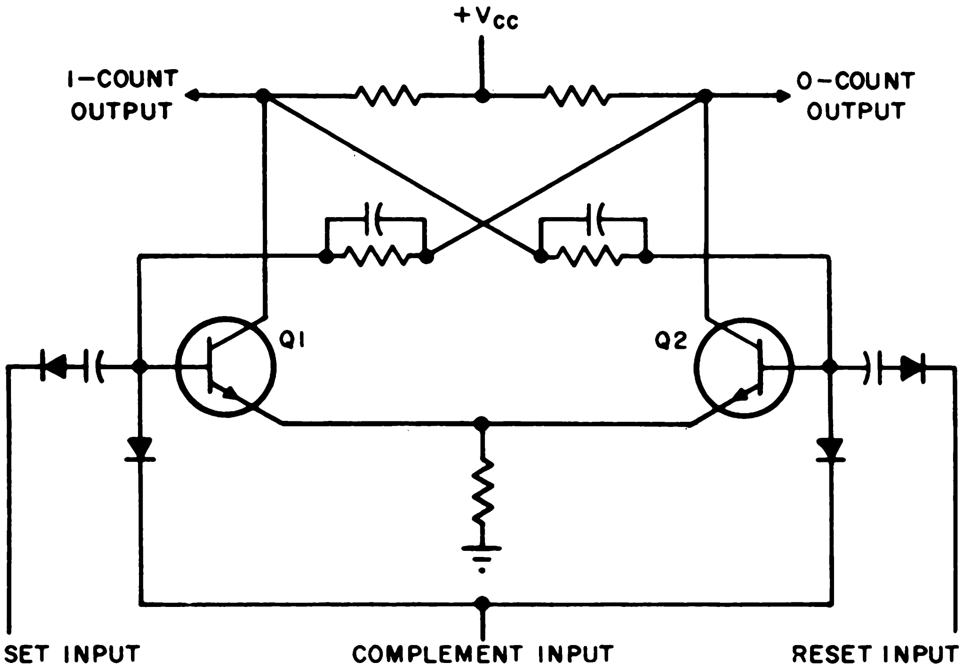


Figure 11-16.—FF using transistors.

basic FF circuit is discussed in Basic Electronics, NavPers 10087-A.) In digital computers, the FF circuit can have several inputs and two outputs. The circuit shown in figure 11-15 (A) has three input signals: a reset input, a complement input, and a set input. Their functions are described below.

A reset input signal sets the stage to a 0 condition or clears the previous 1 count if one was present. If several stages in a counter are cascaded, the reset signal is generally connected to all stages; they are all reset to 0 simultaneously.

The complement (trigger) input is applied to both halves of the FF, and a signal causes the stage to change from a 0 to a 1, or vice-versa. In registers, the complement signal is generally a single pulse that is applied to all stages simultaneously. It produces the 1's complement of the binary number held by the register. In a counter, the complement input of only the first stage could be used as the signal input for the pulses to be counted. The signal and complement inputs can also be applied symmetrically in the plate or collector circuits.

In case the stage is in the 0 state, the set input signal flips it to the 1 state. In most counters, instead of using the complement input, the reset and set inputs of the first stage are paralleled and used for the input signals.

The three inputs use negative signals, to cause a change of state in the FF. It is sometimes desirable to design the stage for positive signals, but a FF stage can be more precisely controlled if it is switched from a state of heavy conduction than from a cutoff state. Note that each stage counts to a scale of 2, but indicates a maximum count of only 1, a 0 would be indicated for a second input pulse.

Counters

Most large computers can handle a maximum of about 34 bits, the equivalent of a 10-digit decimal number. The maximum scale for a binary counter is equal to 2^n, where n is the number of FF's. However, the maximum decimal equivalent count that the indicators will show is 2_n -1. Figure 11-17 shows four FF's that make up a binary counter capable of counting to the binary equivalent of decimal 16. If indicators are provided that read in the binary number system, a count equal to 15 in the decimal system is indicated as 1111. The next count, which is decimal 16, changes all the indicators to 0.

The decimal positional coefficients of binary 1111 are 1, 2, 4, and 8, read from right to

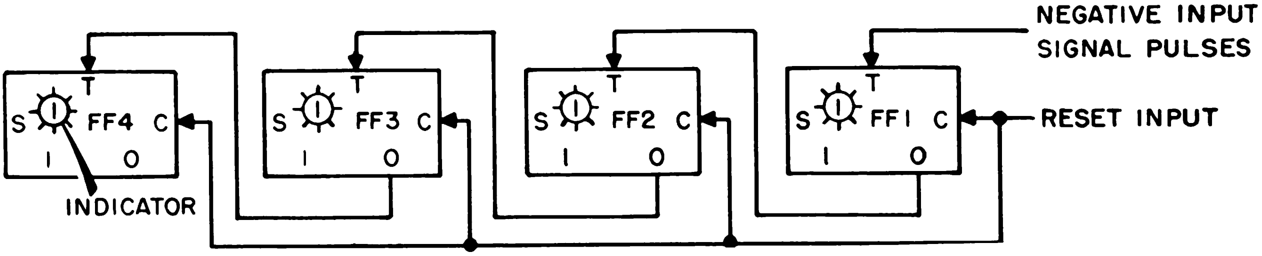


Figure 11-17.—Binary counter at a count of 1111 (decimal 15).

left. The least significant bit (LSB) is the last 1. For a count of binary 1, the binary indicators would read 0001; for this reason the drawings for binary counters and registers sometimes show the input pulses applied to the right-hand side of the chain and the signal and count progressing to the left. However, an oscilloscopic presentation of the input pulses will show the pulse that represents the LSB as the pulse which is furthest to the left on the oscilloscope screen.

A counter similar to the one shown in figure 11-17 is explained in detail in Basic Electronics, NavPers 10087-A. That explanation should be reviewed before continuing with the present discussion.

It is easy to convert the counter of figure 11-17 into a decade (scale of 10) counter (fig. 11-18) by the use of feedback. In the case of decade counters, indicators which read from 0 to 9 can then be provided. Other feedback and feed-forth arrangements will also convert four FF's into a decade counter.

The counter of figure 11-18 operates in the same way as the one shown in figure 11-17, with two exceptions:

1. On the fourth input pulse, FF3 flips to the 1 state, feeds back a positive pulse to the set input of FF2, and sharply flips it from the 0 to the 1 state. At this point the counter registers a decmal 6 (0110 in binary), a condition that the circuit of figure 11-17 reaches after 6 input pulses. In other words, the circuit in figure 11-18 jumps ahead by two counts after the fourth input pulse is applied.

2. The sixth input pulse flips FF4 to the 1 state; and a positive pulse is fed back to the input of FF3, sharply flipping it back to the 1 state. At this point, the circuit registers 12 (0010 in binary), since after a full count of 9 is returned to 0 at 10 and is now back up to 2, and the counter is ahead by 6 counts.

Otherwise, the FF's respond to the 10 input pulses in a normal manner, taking into consideration the states of FF2 and FF3 after feedback is applied.

So far, the counters have been described as counting upward; counting downward is also easily done with FF's by simply feeding the 1 output, instead of the 0 output, to the normal input of the next FF. This is frequently done in digital computers.

Types of Input

Binary words are fed into the logic and arithmetic circuits in either of two different forms, serial or parallel, or in a combination of the two. In serial form the bits follow one another sequentially on a single input line. In parallel form, all the bits of the word are applied simultaneously over a number of paths equal to the number of bits in the word. Figure 11-19 illustrates both methods.

Each method has advantages and disadvantages. The method used in a particular computer depends on whether extremely high speed arithmetic operations are needed or whether economy and machine simplicity are more important.

A machine with serial operation is much more economical. For example, in the case of a counter or register, a word representing decimal 15 (1111 in binary) can be handled by four FF's; and, as will be shown later, there is no limit to the word length a serial adder will handle.

A parallel counter or register for handling binary 1111 also requires four FF's, but its speed of operation is four times faster than the speed of a serial counter or register. However, 30 FF's would be required for a parallel 30-bit word. In a parallel adder, a separate adder is required for each bit of both the addend (the number that is to be added to another)

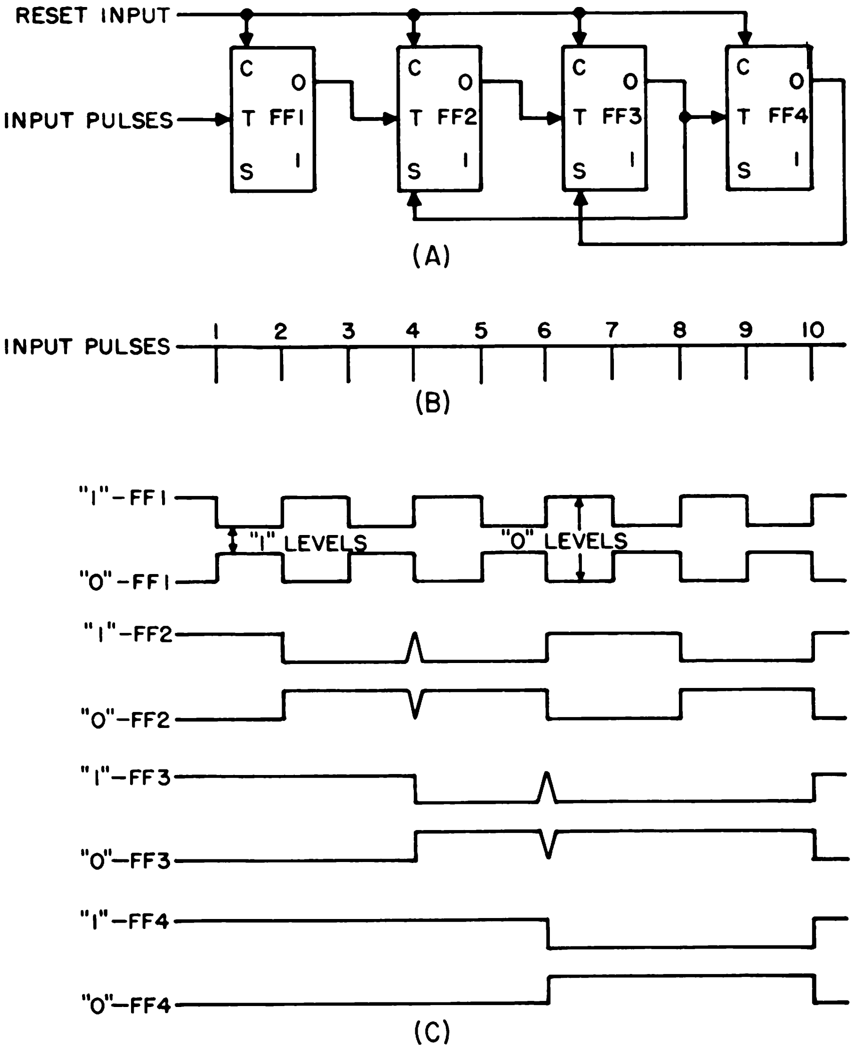


Figure 11-18.—Coversion of a scale of 16 binary counter to a scale of 10 counter. (A) Counter circuit; (B) clock input pulses; (C) waveforms.

and augend (the number to which another is to be added). However, the addition is completed in the same time a serial adder requires to add one-bit addend and augends. The complexity of a parallel arithmetic unit over a serial unit is multiplied by the word length.

Registers

A register is a device that provides temporary storage of a binary word during computation. Registers are composed of FF's and are generally found in the control and arithmetic units of digital computers. There may be several in a large computer; however, an arithmetic unit may contain only one or two. The number depends on the amount and variety of other storage facilities that are included. It is also somewhat dependent upon the speed with which the computer is designed to operate. A relatively long time is required for readout of a word from a magnetic drum memory; a shorter readout time is possible with magnetic core matrix and sonic delay line type memory units. Generally, one or more arithmetic registers can be used to advantage in speeding up the computation.

Remember that a word is a group of pulses; each pulse, or lack of one, represents a bit; each bit represents a binary digit of 1 or 0. The chain of bits can be of almost any length;

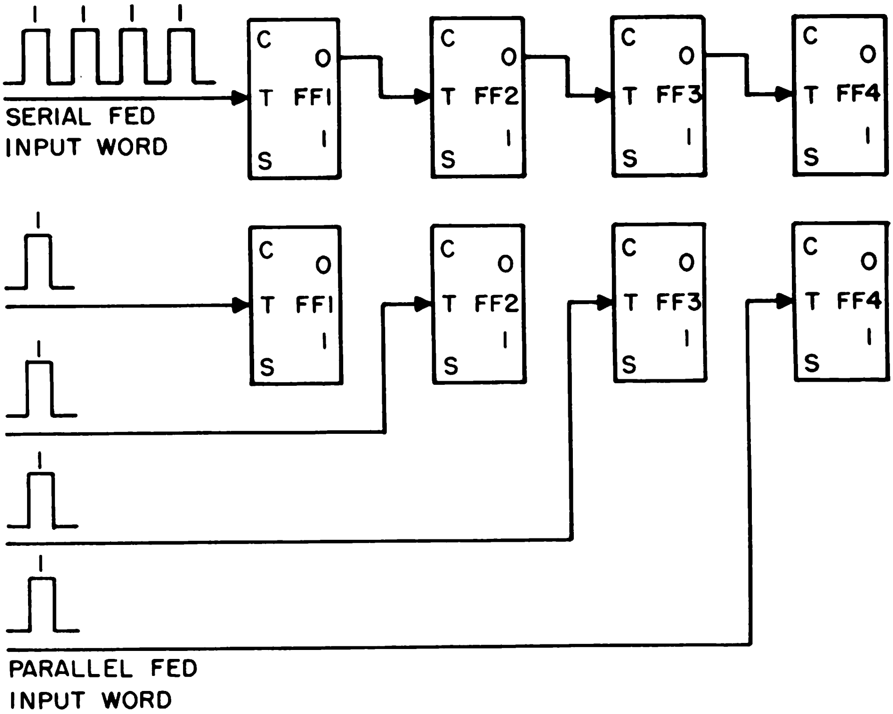


Figure 11-19.—Examples of serial and parallel inputs.

e maximum is usually about 34 bits. This oup of pulses at the input unit can represent structions, constants, and variables for the roblem. In the actual arithmetic circuits, the lse chains that represent the constants and riables for the problem are present. The struction portion of the word is used to program e computer.

STORAGE REGISTER.—A storage register used to store a word temporarily. Storage gisters consist of a group of FF's capable storing the maximum word length expected; ey operate in the same fashion as counter F's. Figure 11-20 represents a storage reg- er which is capable of handling a four-bit ord. The lower group of FF's comprise the gister, and the upper group form an associated unter. Between the two is a group of AND rcuits. Note that the input to the counter is serial form and the input to the register is in rallel form; therefore, it also forms a serial to rallel converter for the word. (The counter is cluded in the set because of this function as a nverter.) First, the word is applied to the unter. Later a read pulse is applied to the AND rcuits. If the read pulse and the voltage at the 1 output of a particular counter FF agree in voltage levels, a 1 pulse is transmitted to the corresponding register FF. No signal is transmitted to a register FF if the 1 output of the corresponding counter FF is at a 0 voltage level, or, in any case, until there is a read pulse applied.

Each register FF can store a signal bit, representing a 1 or 0. Note that at the same time a 1 is represented by a 1 level of voltage at the 1 output terminal, a 0 voltage level is represented by the 0 output terminal. In other words, if a 1 output represents A, the 0 output represents $\overline{A}$. The output from the lower FF's (fig. 11-20) might be applied to the augend or addend terminals of a parallel adder circuit, the other word being supplied by similar means. If both the 1 and 0 leads are connected to other circuits, the condition is known as "double lead transfer" of information.

An extra bit is included in an information word to indicate the sign of the binary number. A three-bit word such as +110 would be fed into the counter or register as 0110, where the first 0 (MSB) would indicate a positive number. A negative 110 would be 1110. Therefore, the circuits that handle signed words must have an extra FF to handle the sign bit.

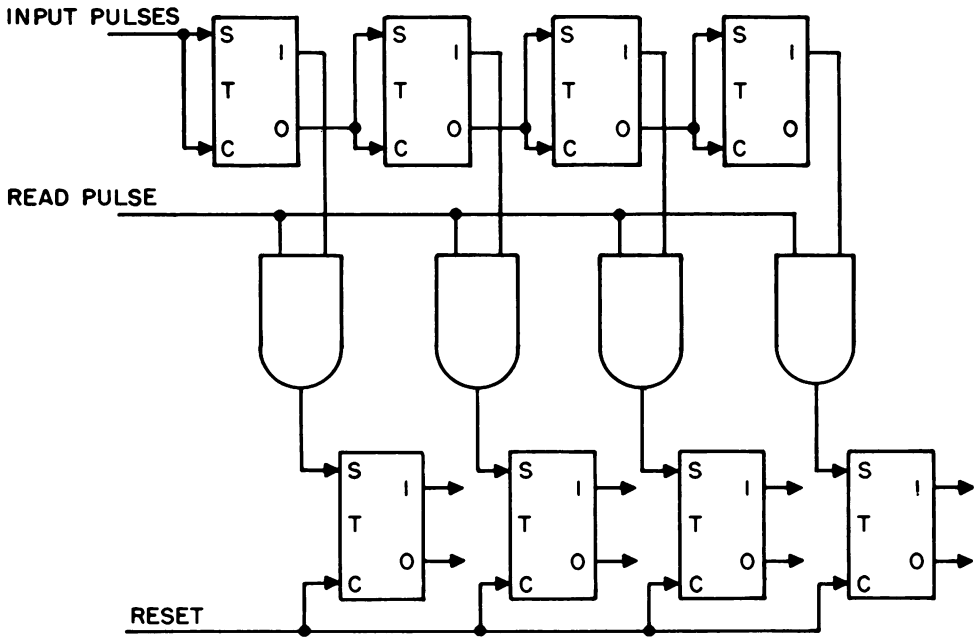


Figure 11-20.—A four-bit register and associated counter.

A storage register and serial to parallel converter that does not use an associated counter are shown in figure 11-21. Delay lines (D) are used in this instance to provide the conversion from serial to parallel. Each delay line introduces a delay equal to the input pulse spacing. Therefore, the first input pulse (the one on the left) arrives at A4 at the same instant that the last bit pulse is applied at A1. The input pulse spacing is the same as that of the clock pulses for serial form. Therefore the read pulse would be taken from the clock, but it would not be applied to the AND circuits before the last input pulse was applied to A1.

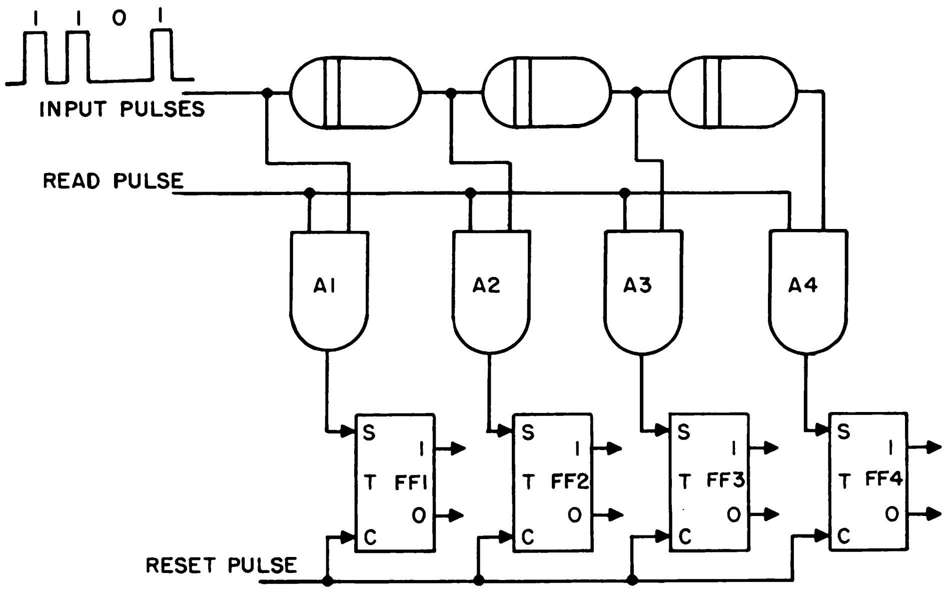


Figure 11-21.—Storage register using delay lines.

With the exception of the delay line feature, the circuit is the same as the one in figure 11-20.

SHIFT REGISTER.—A shift register is a storage register in which the stored number can be shifted left or right with a shift pulse. (See fig. 11-22.)

The shift pulses are applied continually, and they have the same spacing as the bits of the word. But since the FF would be upset if a shift pulse and a bit pulse occurred simultaneously, the shift pulse is applied midway between bit pulses. The FF's are so coupled that any particular one is set to a 1 state only if the preceding one was reset to 0 by the shift pulse. The delay lines (which may be RC circuits) have a delay that is only a small portion of the spacing between pulses. The operation of the shift register is discussed in the following paragraphs.

Assume that the binary word 1101 (decimal 13) is to be stored. The first 1 bit is applied and sets FF1 to 1. This does not affect FF2. A shift pulse then occurs that resets (clears) FF1 to 0; and FF2 receives, after a short delay, a pulse from FF1 that sets it to 1. Then the second 1 bit is applied to FF1, setting it to 1 again. Now both FF1 and FF2 are set to 1; and another shift pulse occurs, resetting them to 0. Shortly thereafter, FF2 and FF3 are set to 1. The next bit in the word is a 0 and has no effect on FF1. The following shift pulse resets FF2 and FF3 to 0; later, FF3 and FF4 are set to 1. FF1 and FF2 now read 0. The last bit sets FF1 to 1. Shift pulses are stopped at this point, and binary word 1101 has been stored.

The application of four additional shift pulses causes the stored word to be read out the left side of the register. The contents can be read out to additional FF stages, to the memory unit, or to adder circuits. The ouput might also be returned to the input, through pulse reshaping amplifiers, to form a dynamic (circulating) type register.

If the register contains many more stages than there are bits in the stored word, the stored word can be shifted to the left and its changing value doubled by each successive shift. For example, if the word 1101 (decimal 13) is shifted to the left by 1 bit, the register will read 11010 (decimal 26). If 11010 is shifted to the left again, the register will read 110100 (decimal 52). Therefore, each left shift multiplies the register word by binary 10 (decimal 2). Note that the decimal point location in this particular register does not shift. In this case, it remains at the input terminal, or to the right of the last stored bit.

Additional stages must be switched into the right-hand side of the register before the word 1101 can be shifted to the right. Assume that 1101 is stored and it is desired to shift it to the right. The decimal point is fixed at the input terminal point. Now, additional FF's are switched into the right side of the register, and a shift pulse is applied. The register will now read 110.1 (decimal 6.5). Thus the stored word has been divided by binary 10. Another shift pulse would produce 11.01 (decimal 3.25).

ACCUMULATOR.—Of the various types of registers found in an automatic digital computer, the type which is most important has the capacity to store a word, then receive additional words and sum the total. A register with these features is defined as an accumulator. It will most likely also incorporate left and right shifting features and be capable of dynamic operation. It must be able to provide this additional feature

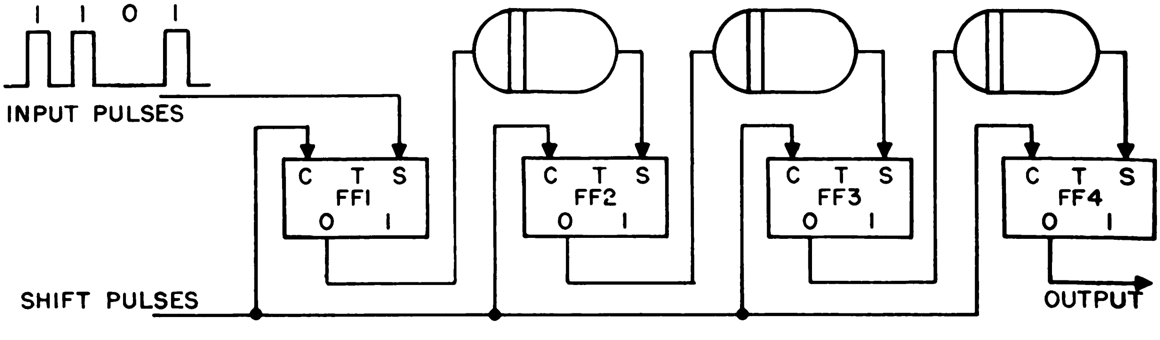


Figure 11-22.—Shift register.

while handling the maximum computer word length.

Figure 11-23 presents a simplified block diagram of a serial arithmetic unit and indicates the importance of the accumulator. The accumulator can receive or send information to the memory unit; the stages of the shift register can be added to the accumulator to form a double length accumulator during multiplication and division; and the complement register can be complemented and its contents added to the contents of the accumulator. The importance of the relationship displayed by this block diagram will become clear during a discussion of adders and the computational processes.

ADDERS

It has already been pointed out that a counter can total the number of pulses in a word and store the word temporarily. It was also mentioned that the accumulator is very flexible in this respect; it can receive several words, add them, shift them right or left, and store them. However, the counter and the accumulator are limited in the word lengths they can handle or store. A serial adder has no word length limitations; it is limited only by the storage capacity of the memory unit.

These adder units do not contain new kinds of circuits; they are made up of the basic logic circuits that have already been discussed.

Serial Adders

The half adder is the basic adder circuit for binary addition. It is called a half adder because it performs only the lowest order of addition—it has no input terminal for a carr Remember, a carry (C) is generated when and 1 are added to given a sum (S) of 0, producing a C of 1. Figure 11-24 is the block diagram and input/output table for a half adde

Notice, in figure 11-24, that the S (su output is in the 1 state only when A and B ar unlike. This is expressed by the equatio S = A'B + AB', where A' and B' have th same meaning as $\overline{A}$ and $\overline{B}$. This is the EXCLUSIVE OR function discussed earlier, an can be mechanized as shown in figure 11-2

Assume that A = 11 and B = 101. Th first two bits of each word are applied simultaneously and produce a 1 output from th OR and AND circuits, but the S ouput is 0 because of the inhibit action. The 1 from the AN circuit is the C output. The next set of bit a 1 and a 0, produce an S output of 1. The la set of bits, a 0 and a 1, produce an S output 1. Checking the S output, the result is see to be 110, with a C output of 1. This could b considered a wrong answer; but, if the carr could be utilized during the addition proces the correct answer of 1000 would be produce

To utilize the carry during the additio process, two half adders and a delay line ca be employed as shown in figure 11-26. Thi combination is known as a full adder. Each ha adder (fig. 11-26) consists of an EXCLUSIV OR circuit.

The first two 1 bits of A and B produce onl a C1 carry of 1 from the first half adder, an S1 is 0. C1 is delayed by an amount equal t the bit spacing before being applied to the secon half adder. The second set of A and B bits ar a 1 and a 0, respectively. This results in a S1 of 1 and C1 of 1 being applied to the secon half adder, producing an S output of 0 and a output of 1. This 1 of the C output is fed bac delayed, and applied to the second half adde At the same time, an S1 output of 1 is produce in the first half adder and applied to the secon half adder. This results in another 0 at the

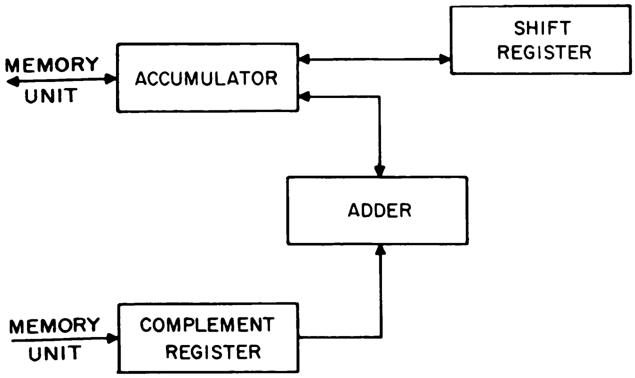
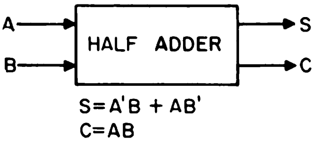


Figure 11-23.—Simplified block diagram of a simple serial arithmetic unit.



INPUT		OUTPU	
A	B	S	C
1	1	0	1
1	0	1	0
0	1	1	0
0	0	0	0

Figure 11-24.—Half adder block diagram and input/output table.

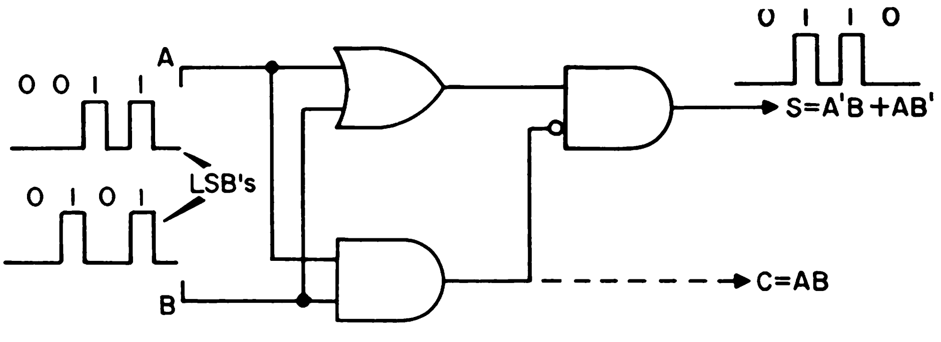


Figure 11-25.—Half adder (EXCLUSIVE OR) circuit.

output and a 1 at the C output. Now this C is delayed and applied to the second half adder again. A and B are 0 at this time, and the second half adder receives an S1 of 0. This causes the second half adder to produce an S output of 1 and a C output of 0. The result of the addition is now correct:

$$A = 11$$

$$B = 101$$

$$S = A + B = 1000$$

Note that this is strictly arithmetic addition of binary numbers 11 and 101, not Boolean algebra addition.

Parallel Adders

Parallel addition is used where computational speed is important or for adding binary coded decimal (BCD) words. Figure 11-27 shows the block diagram of a parallel adder, which is nothing more than four full adders with parallel inputs and the carry applied serially between stages.

Assume that two decimal numbers, 3471 and 1318, are to be added as BCD numbers, using the 8421 code for conversion into BCD. The decimal 3471 would become

A1	A2	A3	A4
0011	0100	0111	0001

and 1318 would become

B1	B2	B3	B4
0001	0011	0001	1000

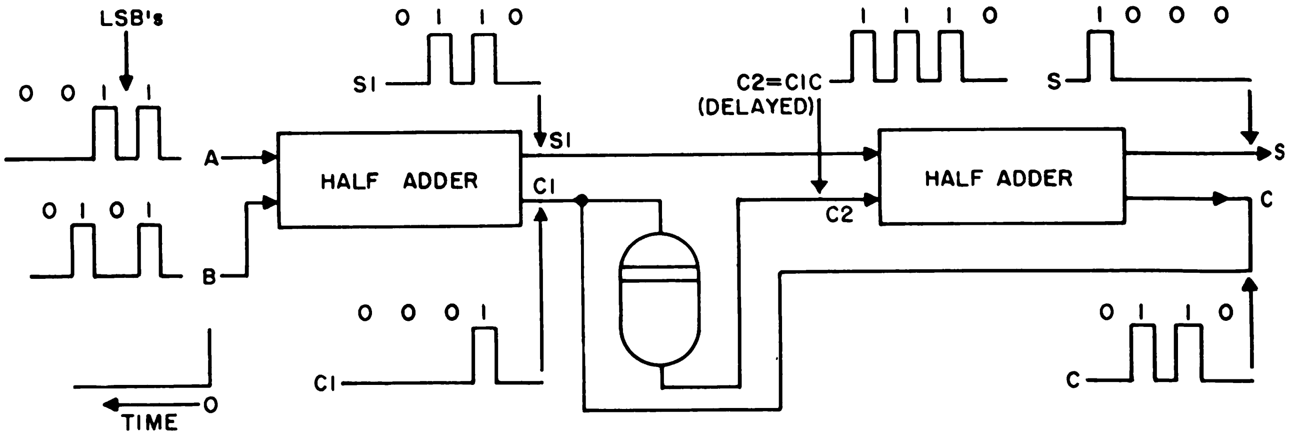


Figure 11-26.—Full adder block diagram and bit trains.

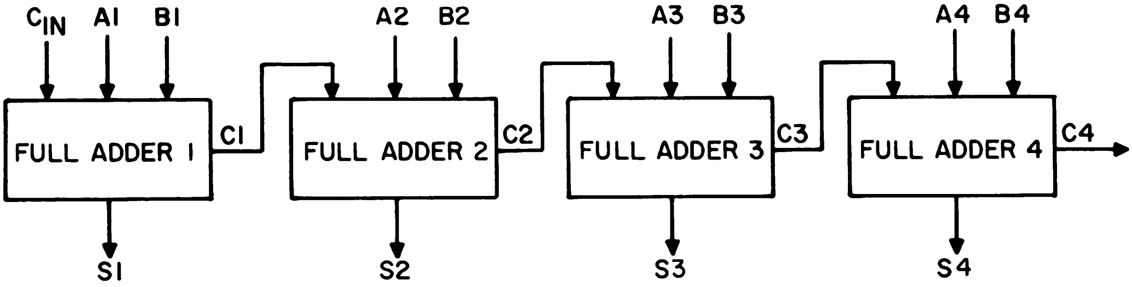


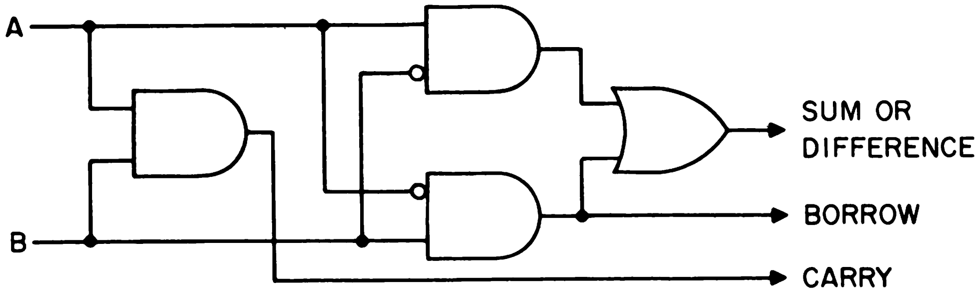
Figure 11-27.—Parallel adder.

The bits in each group A1, B1, etc., are applied serially to the correspondingly designated terminals, but each group is applied simultaneously. The C_{in} comes from a previous adder, the C4 and the sums would be A or B inputs to a higher order adder if it were necessary to add three decimal numbers. This adder could also be used to add two four-bit pure binary words or for the parallel-bit addition of four serial words.

One point needs clarification. It was assumed that each partial carry was produced with no delay between bit input and carry output. This cannot be achieved in practice; therefore, the A and B inputs down the chain must be delayed enough to allow the respective carry to appear at the time the A and B inputs are applied down the chain.

Adder-Subtractor

An arrangement of logic circuits is possible that will perform either addition or subtraction. The half adder-subtractor form of such a group is shown in figure 11-28. It is composed of one AND gate, two INHIBITOR gates, and one



INPUTS		OUTPUTS			
A	B	SUM	DIFFERENCE	CARRY	BORROW
0	0	0	0	0	0
1	0	1	1	0	0
1	1	0	0	1	0
0	1	1	−1	0	1

Figure 11-28.—Half adder-subtractor and input/output table for addition and subtraction.

OR gate. A carry is generated by the AND circuit and used during addition. During subtraction of binary numbers a case occurs where there is a borrow of 1. This 1 can be borrowed from the output of one of the INHIBITOR circuits.

Two half adder-subtractor circuits can be used to form a full adder-subtractor, with an additional OR circuit and a delay line having a delay equal to bit spacing in the words, as shown in figure 11-29. Addition uses the carry output of the first half adder and the feedback from the second one for application to the OR circuit. During subtraction, the borrow output of the first half adder-subtractor is applied, via the OR circuit and delay line, to the second half adder-subtractor, and the borrow from the second one is fed back to the first one.

COMPUTATION

The actual computational details-addition, subtraction, multiplication, and division—vary from computer to computer because different models have different circuitry in the arithmetic, memory, control, and output units. The registers and adders will also vary in different models. Therefore, since it is impossible to describe all circuit variations and the ways that they function, only a general description of possible computational processes will be given.

Addition

The general idea and methods of addition should be clear at this point. A word, called the augend, is taken from the memory and put into a register, generally, the accumulator. A second word, the addend, is taken from the memory and added to the augend. The result is stored in the accumulator, sent back to the memory, or used for addition to another word. The adders will be used for words whose length exceeds the accumulator's capacity.

Subtraction

Subtraction can be performed by complementing the addend and adding it to the augend. Registers generally have provisions for complementing their contents. Some computers use the 1's complement, which is found by substituting a 1 for each 0 and a 0 for each 1 in the digits (bits) of the binary number; others use the 2's complement. The adder-subtractor

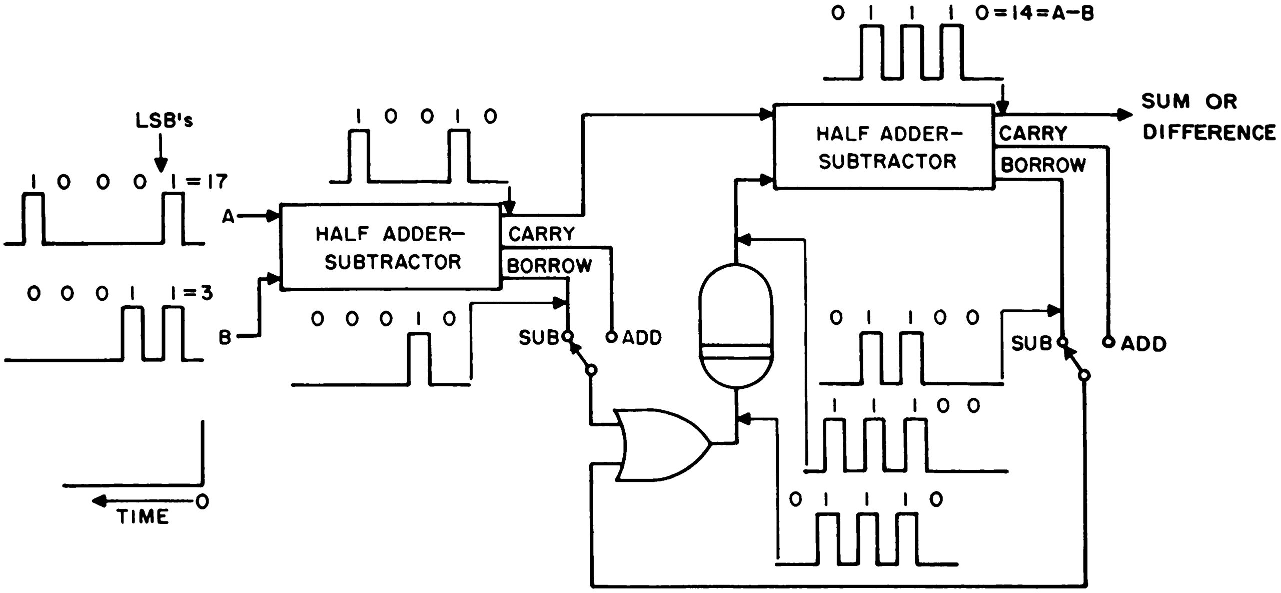


Figure 11-29.—Full adder-subtractor, with waveforms for the subtraction of decimal 3 from decimal 17.

can also be used to find the difference between two words.

Multiplication

Multiplication is really repeated addition, shifting left, or a combination of both. The accumulator is usually a register whose contents can be shifted left or right; or a second shift register can be used, and the accumulator can be used to store the result. Circuitry is provided to count the number of additions, which will be equal to the number of bits in the multiplier.

Division

In about the same manner that multiplication is accomplished by repeated addition and shifting left, division is performed by repeated subtraction and shifting right. In case the last subtraction results in a negative remainder, this is detected by special circuitry; and the last subtracted amount is restored. The subtraction part of the division process can also be done by complementing and adding.

MEMORY UNITS

The kind of storage employed by an automatic digital computer is decisive in determining the form a computer may take. A computer's storage or memory is sometimes referred to simply as a store.

LEVELS OF STORAGE

Internal storage refers to storage which the programer, or coder, would normally use. It is located within the arithmetic unit or main storage, and is characterised by high speed and low capacity.

Secondary storage is cheaper and slower in access, but it has larger capacity—perhaps hundreds or thousands of times as much. Access time could be as small as milliseconds for nagnetic drums or up to minutes for magnetic tapes. Blocks of secondary storage are normally referred to the arithmetic unit as required, instead of direct reference to a specific storage location of a specific stored word.

External storage refers to punched cards, punched tapes, and magnetic tapes stored in files or cabinets, which the computer does not have direct access to. External stored information is in a form which the computer can use, but it is physically separate from it.

The capacity of a store is measured by the amount of information in bits or (binary) decisions it can store. The storage capacity of a flip-flop is one bit. A register can store one word at a time, but an array or matrix of magnetic cores may store 10,000 words with fairly small bulk (each core may have an outside diameter of only 50 mils). The storage capacity of magnetic tapes used for external (slow access) storage may be essentially without limit.

Access time refers to the time required to write in and read out information from storage, including the time to communicate with the storage location. If destructive readout is employed, the ''destroyed'' information must be written back in before the cycle is complete. Random access is said to occur if access to any storage location is independent of the storage address of the previous word. Access is said to be cyclic if the access time depends on the location of the previous word, as in the case of a rotating magnetic drum. (With a rotating magnetic drum, the addresses available at any given instant depend on the instantaneous drum position.)

Random access time for internal storage may be typically a few microseconds, but for secondary storage, milliseconds to minutes will be required.

Static or dynamic storage refers to whether the information changes location or not (when it is not being used). Examples of static storage devices are flip-flops and magnetic cores. Examples of dynamic memory devices are delay lines (with circulating pulse trains) and rotating magnetic drums.

Erasable storage is widely used in computers since it is essential in many instances to be able to store different words at different times at the same storage location. Examples of erasable storage include magnetic drums and magnetic tapes. Examples of nonerasable storage are punched cards and punched tapes.

Volatility relates to the loss or alteration of stored information due to an unintentional power loss. Regeneration or the periodic reinforcement of stored information, which is a common practice in dynamic storage, usually results in a volatile situation.

Serial (series) or parallel access refers to reading or writing one bit at a time or simultaneously. When all bits of a word are transferred in the same cycle, operation is said to be parallel. Only the smaller binary computers are entirely serial in storage access; on the other hand, very few computers use parallel storage systems altogether. Most use a series parallel arrangement. A parallel arrangement provides high speed at the cost of a great amount of additional equipment. On the other hand, a completely serial situation is usually too slow.

RECIRCULATING STORAGE

Dynamic storage requires by definition that the stored information be moving. Therefore, it becomes necessary to recirculate the signal over a given path to prevent running out of path if storage is required for more than a very short length of time. Presented in its most basic terms, the situation in figure 11-30 applies.

Clock Pulses

An idea which is basic to most digital computation is that of a uniform rate of counting (operating) or synchronous operation. To obtain this, a clock, or master clock as it is sometimes called, is employed. This clock controls the rate of, or produces, clock pulses. The spacing between these pulses defines the interval during which an event can occur.

If the signal is delayed for n (clock pulse) intervals and is fed back to the input of the AND circuit as shown, it will be continuously regenerated by the action of the AND circuit, thus storing n bits of information in the loop. The AND circuit produces an output signal only when both inputs are present, that is, in the 1 condition. When the delayed signal is in the 0 condition, the output will be a 0 signal. The delay can be any convenient length and may store hundreds or thousands of digits. Accordingly, such a scheme is rather economical.

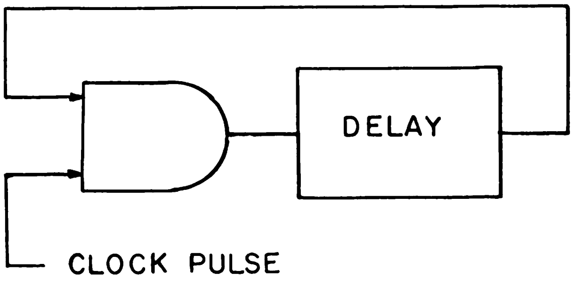


Figure 11-30.—Basic storage unit, block diagram.

DIGITAL MAGNETIC TECHNIQUES

The process of recording a 0 or a 1 on a magnetic medium (consider tape, for example) appears straightforward enough, and is; but the techniques used vary considerably from those used for the more familiar recording of speech. The two opposing problems are to obtain the highest packing density (the number of stored bits per inch of recording tape) and to maintain reliability. To obtain a reasonably high packing density, it is obvious that some distortion can be tolerated.

To record digital data efficiently, a saturation amplitude signal is normally employed. This results in a memory output signal which is a gross distortion of the pulse being recorded. In fact, the signal which is read back is essentially the derivative of the pulse which is read in, or recorded. This is true because, when the magnetic medium is saturated, the output winding "sees" no change in flux and therefore produces no signal. The only time a signal is produced, then, is when going into or coming out of saturation. (See fig. 11-31.)

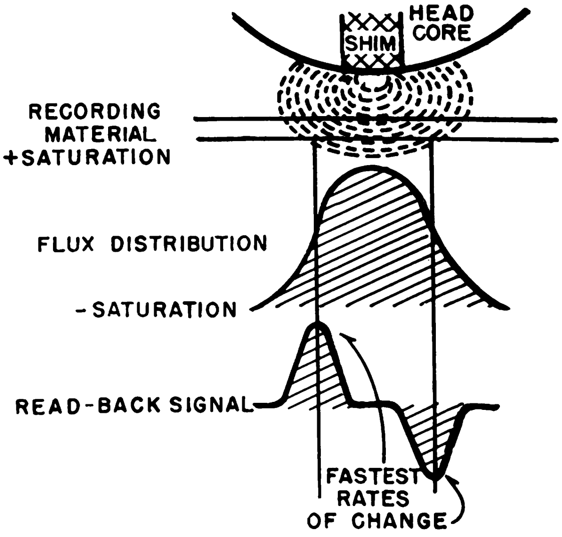


Figure 11-31.—Magnetically recording a pulse.

The amplitude of signals recorded may be wo-level or three-level, depending on whether condition of zero magnetization is allowed to ccur other than instantaneously. See waveforms A) and (B) of figure 11-32. Sometimes non-eturn to zero techniques are used so that a vaveform such as that shown as waveform (C) f figure 11-32 occurs. Notice that no change f output level occurs when succeeding digits re the same (two successive 1's, for instance). 'his means that no playback signal (pulse) vould appear at this time. With a long series f 1's, it becomes apparent that timing pulses ecome a necessity; otherwise counting the ime intervals would become very difficult.

In fact, it is generally necessary to devote recording track to the sole purpose of re-ording timing or synchronizing signals (pulses).

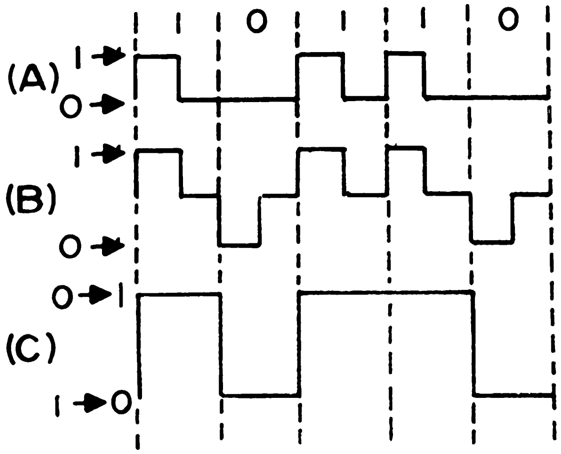
Since the playback (readout) signal waveform s usually of a different shape than that of the eadin signal, it is often processed to restore t to the original shape.

AGNETIC DRUMS

A magnetic drum is the cheapest form of nternal storage for a small computer; the data tored on the drum is erasable but nonvolatile not lost when power is turned off).

The magnetic surface of a rapidly rotating rum such as that shown in figure 11-33 is a very economical main store for a small computer. Rotating at a speed of several thousand rpm, a track spacing of several tracks per inch may be obtained. Each track has the capacity of storing many bits, normally in the thousands, depending on the drum size, speed, and so forth.

Heads for writing on or reading from the drum, figure 11-34, are mounted so that the



igure 11-32.—Waveforms for binary number 10110. (A) A two-level system; (B) a three-evel system; and (C) a nonreturn to zero system.

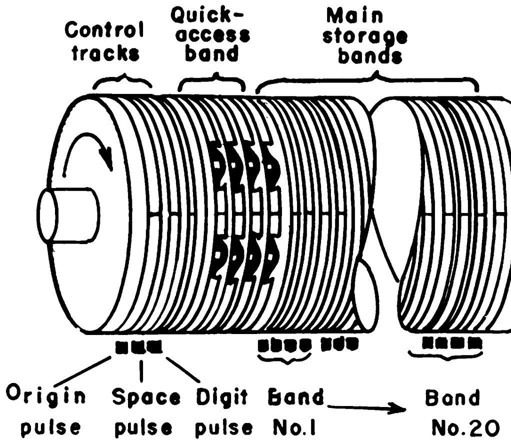


Figure 11-33.—Magnetic drum.

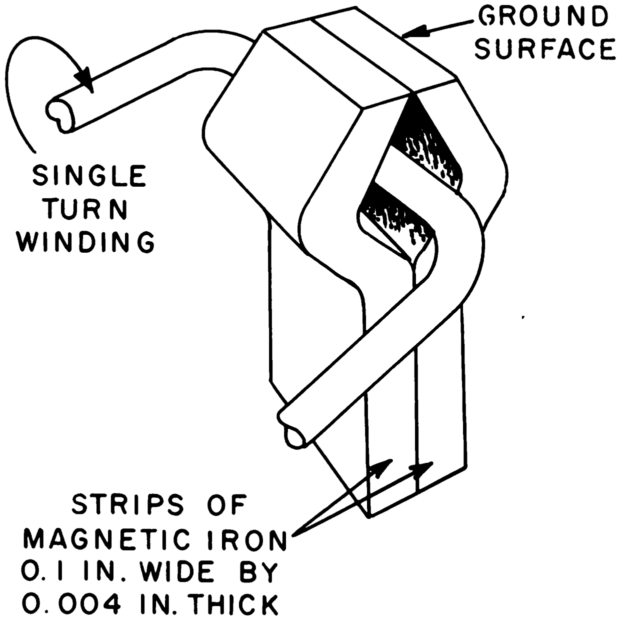


Figure 11-34.—Magnetic drum head.

drum rotates past and in close proximity to them.

Access to data stored on the drum depends on the rotational speed and the location of the particular data desired. When the desired data has just passed the head, access time is maximum—one revolution. If the desired data is under the head, access time is nearly zero. Thus, for the general case, average access time is half of a drum revolution, but by ''optimum programing'' this can be reduced.

The drum shown in figure 11-33 includes a quick access band, each track of which is composed of several recirculating loops. These loops waste the portion of track, if any, which is not between the two heads that comprise a loop.

Magnetic drums vary greatly in capacity and operating speed. Speeds of 3,000 to 17,000 rpm and diameters of 4 to 12 inches result in average access times of 2 to 10 milliseconds.

MAGNETIC DISK

The magnetic disk, figure 11-35, is similar to a phonograph record except that the tracks are circular instead of spiral. The spacing of the recording heads is maintained by an ''air bearing.'' A very high storage capacity is characteristic of this type of storage. Its low mechanical inertia makes it appealing for airborne applications. Disk storage has been built with 100 concentric tracks on each side of each disk.

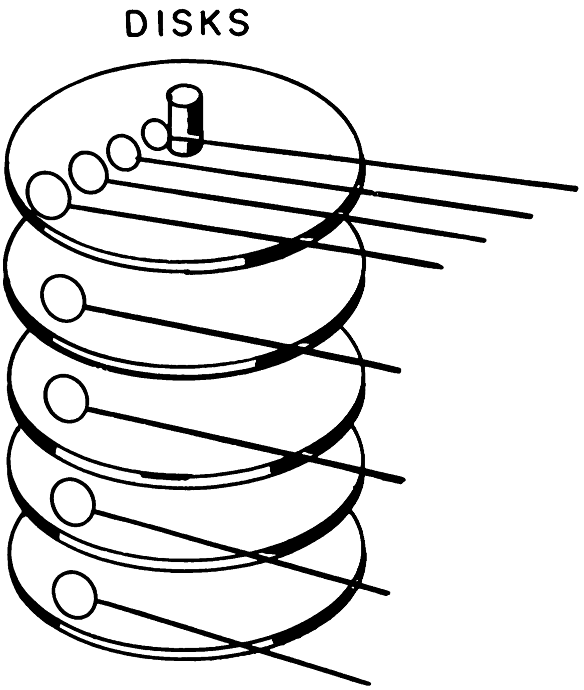


Figure 11-35.—Magnetic disk diagram.

MAGNETIC TAPE

Perhaps the most familiar type of storage to the Navy technician is magnetic tape. The materials used may be the same as those used for audio recording, except that very high quality tape is required to avoid missing an occasional bit.

Seven channel tape is usually one-half inch wide. Its recording density is normally from 100 to more than 500 characters per inch of tape. Thus a 2,400-foot roll can store about 3 to 16 million characters. This is less than the apparent maximum because the gap between recorded sections of tape may be from 1/2 to 2 1/2 inches. Obviously, the tape must be brought up to speed before reading or writing is begun. A 2,400-foot tape with 200 characters per inch holds as much data as 25,000 cards, each 80 columns wide. Tape speed may be as high as 240 inches per second.

Under ordinary operating conditions, magnetic tape is usuable up to 50,000 times; data on a used tape may, of course, be transferred to a new tape. Temperature and humidity variations may cause the oxide surfaces to crack, and dust may cause a signal to be missed. Oil or moisture from manual handling may encourage the collection of dust.

MAGNETIC CORES

Large computers employ many small toroidal (ring or doughnut shaped) cores made of ferrite, each of which can store one bit of information by becoming magnetized. The magnetizing force required is modest, since a single conductor passed through the core will suffice to perform the function of a winding. An array of such cores, typically each only about one-twentieth of an inch in outside diameter, was mentioned previously.

By arranging these cores in a rectangular matrix or array, very short access times are common because parallel access is practical with the use of modern high speed semiconductor switches. Access times of less than 10 microseconds are practical and commonplace.

By coincident current techniques, any single core may be selectively readin or readout. That is, by passing a current through a given core, the two fluxes may be made to add and to exceed the threshold value necessary for switching the selected core. (See fig. 11-36.)

The use of a third winding permits sensing the switching of a core. That is, if interrogated by two coincident (additive) half-select pulses, the core will switch and the change of flux will induce a pulse into the output winding. Obviously, half-select pulses will be passed through a core often when reading into or writing out of adjacent cores, but these should cause no harm. Readout causes the core to switch; this is destructive and requires that the information be regenerated if it is not to be lost.

Hysteresis Loops

The hysteresis loop of a ferrite core is essentially square, as depicted in figure 11-36. However, the heavy line which indicates this loop applies only for the case where a symmetrical magnetizing force is applied—certainly not the general computer use situation. A much more realistic representation of the hysteresis phenomena is shown in figure 11-37.

A family of curves such as shown in figure 11-37 illustrates what occurs in a magnetic circuit when excited in anyway other than the simplest way. The solid lines apply when the variable, positive magnetizing force, H, is increasing flux in a positive direction (from P to Q to P'). The dash lines apply when it is decreasing.

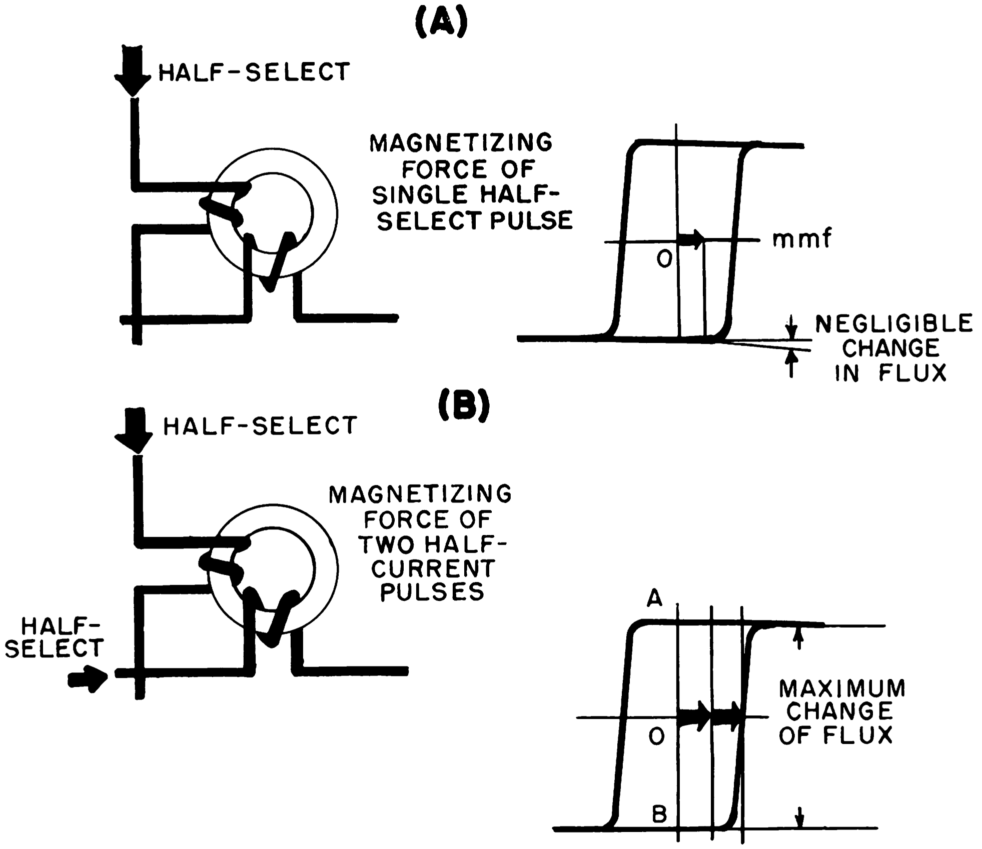

(A)
HALF-SELECT
MAGNETIZING FORCE OF SINGLE HALF-SELECT PULSE
mmf
O
NEGLIGIBLE CHANGE IN FLUX
(B)
HALF-SELECT
MAGNETIZING FORCE OF TWO HALF-CURRENT PULSES
HALF-SELECT
A
O
B
MAXIMUM CHANGE OF FLUX

Figure 11-36.—(A) A single half-select pulse; (B) coincident (additive) half-select pulses.

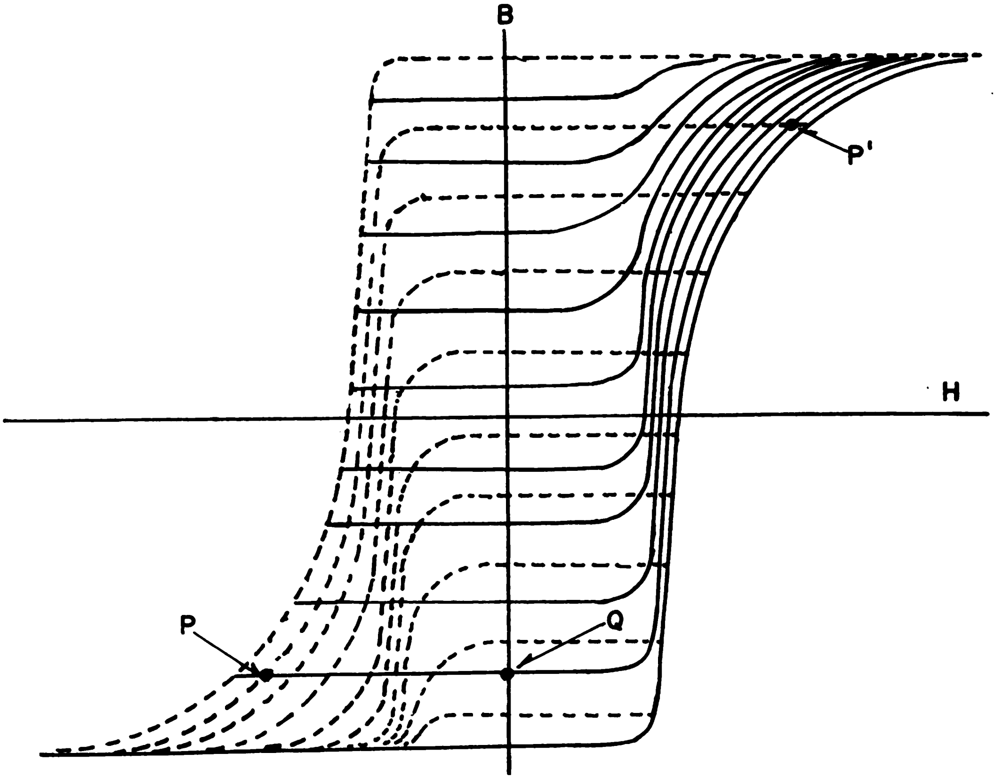


Figure 11-37.—Magnetic hysteresis loops.

Actually, a complete representation would have to show that successive B-H loops do not exactly close; but each time a new loop is formed, it more closely approaches the previous loop, until the difference becomes undetectable after a few cycles.

Testing

A testing waveform of current is used to determine the cumulative effect of half-select pulses on cores. Ideally, of course, a half-select pulse will have negligible effect on a core. In practice, this is not entirely true, as may be suspected.

To determine the effect of many half-select pulses on a given core, the waveform shown in figure 11-38 is applied to a core to be tested. A pickup winding is used to sense the response of the core to this testing waveform, and its signal is applied to an oscilloscope which is synchronized with the testing waveform.

The testing waveform (fig. 11-38) is essentially divided into two parts. Part (a) consists of a write pulse, w, followed by a singl disturbing pulse, d, and a read pulse, r. Par (b) is similar, but includes several disturbin pulses. The response to the two reading pulse is a measure of the disturbance caused by th

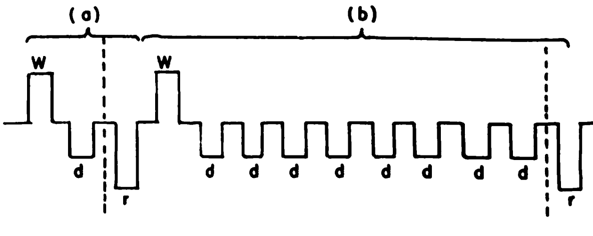


Figure 11-38.—Testing waveform for ferrite cores.

several disturbing pulses (b) as compared with the single pulse in (a). If the response to disturbance pulses is excessive, the cores must be rejected.

OTHER MAGNETIC UNITS

A nondestructive readout device with characteristics similar to the ferrite core just described is called the transfluxer, figure 11-39. In this case, a second, smaller aperture is employed to allow sampling and possible switching of only that portion of flux around the small hole for readout, a procedure which does not switch all of the flux contained by the core.

A thin film dot array memory, figure 11-40, promises very fast, compact and probably inexpensive switching for the future. The feasibility of a cycle time of 0.2 microsecond has been demonstrated.

The magnetic characteristics of this thin magnetic surface (fig. 11-40) are directional in nature. That is, the film is easy to magnetize in one direction, but hard in a direction at right angles to the easy direction. The magnetization characteristic in the hard direction is essentially without hysteresis (instead of a B-H loop, it collapses to a line), but the B-H characteristic in the easy direction is the familiar square loop characteristic.

ACOUSTIC STORAGE

As previously mentioned, delay lines in combination with an AND circuit provide the basic mechanism of dynamic storage. Because, for a given amount of time delay, acoustic (pressure wave) delay lines are less unwieldy (than electromagnetic types), their use has been exploited to a considerable degree. Liquids were first used, including mercury, but many difficulties appeared, even for ground operation. As a result, solid delay media have received much attention.

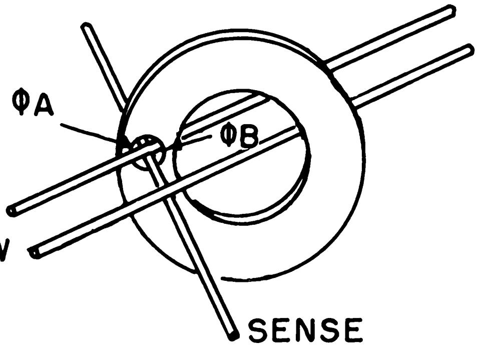


Figure 11-39.—Transfluxer, multiaperture ferrite core.

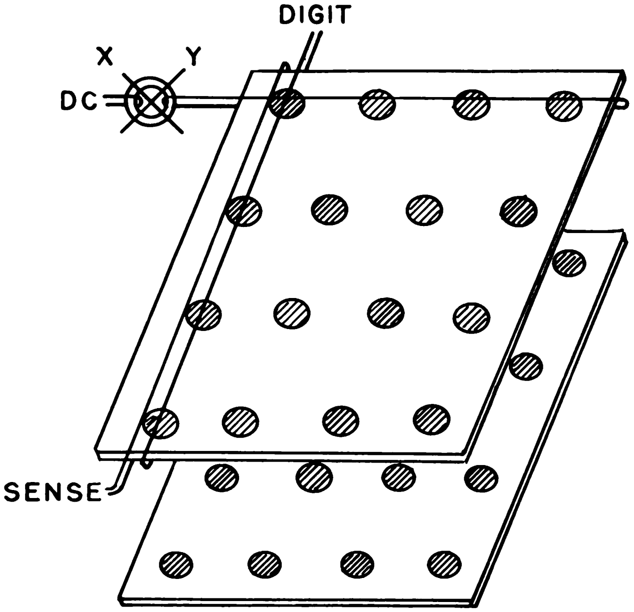


Figure 11-40.—Film dot array memory.

Quartz delay lines have been in the field for quite some time. The piezoelectric effect is employed to impart the signal to the crystal and to recover it. For critical application, such as this, an oven is employed to stabilize against the effects of temperature variations.

A frequent problem with quartz delay units is that more than one type of wave may be propagated. Further; these several waves may have different velocities and polarizations.

Small nickel wires or thin-walled tubes have the advantage of propagating a wave very nearly purely longitudinal in form. Magnetostrictive excitation is employed, as indicated in figure 11-41. The ends of the wire or tube are terminated in some manner to absorb unwanted waves, sometimes clamped by a rubber pad or embedded in a tube of grease.

Excitation directly by pulses is employed. The pulse duration may be a few microseconds. For a given delay, the attenuation is somewhat

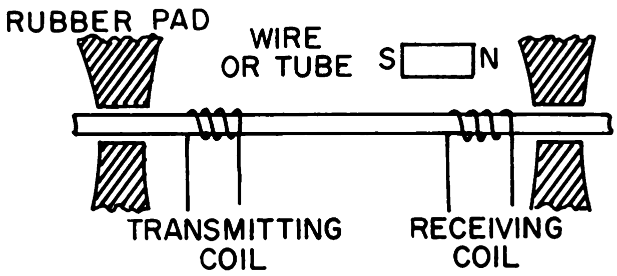


Figure 11-41.—Nickel wire as delay.

less than with a mercury tank. The wire can be bent, which is quite important, since the velocity of propagation of a pressure wave through a solid is considerably faster than through a liquid.

Waveform distortion of considerable consequence occurs with this device. The transducer coils must be physically configured to be compatible with the duration of the transmitted pulse.

Electrostatic storage has been used, but is not expected to have airborne applications.

STORAGE REGISTERS

The internal storage requirement for a very fast-essentially zero-access (and operation) time device with limited storage capacity is accomplished by the use of a register or shift register, which is typically electronic but can be magnetic and may be devised by multiple cascading of flip-flop circuits (multivibrators).

(The usage of the term flip-flop refers to the bistable circuits that make up a shift register.)

The principle of a register is indicated in block diagram form by the string of flip-flops, A, in figure 11-42. Each flip-flop may be set independently and simultaneously by set pulses which may cause each one to assume the 0 or 1 condition to correspond with the binary digits of the particular (binary) number being stored. Thus each bit of a binary word is positionally related to its corresponding flip-flop. Consider that each flip-flop is driven by the one to its left and drives the one to its right in such a manner that, when triggered, the succeeding flip-flop will assume the condition (1 or 0) previously held by its driving circuit. Thus, introducing a pulse representing a 1 or a 0 to the flip-flop on the left causes it to assume the corresponding 1 or 0 condition as ordered, and consequently shifts the condition of each flip-flop to the right one "notch," so that the number which is stored is shifted one notch or flip-flop. What has been described is series shifting. The value of this process may be visualized by remembering that long hand multiplication requires the addition of shifted numbers as a final step in obtaining the product.

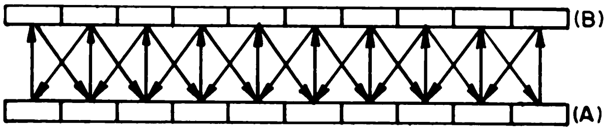


Figure 11-42.—A parallel shifting register.

Another mode of operation is actually depicted by figure 11-42—namely, parallel shifting. In such a case, the number under consideration is transferred from one register, A, directly to a second, B. It may then be returned to A along an oblique path, thus displacing (shifting) it either to the right or to the left, depending on which kind of shift was desired. (In this case, the string of flip-flops, A, are not sequentially connected to each other, nor are those of B.) The output bistable circuit may be fed back to the input to complete the loop, thus accomplishing a circulating loop which may be used to recirculate the stored number or word indefinitely.

INPUT AND OUTPUT UNITS

The input and output units provide the means of communication between the computer and the operator/evaluator. In order to solve problems and process data, the data and instructions must be inserted into the computer, and the computer must deliver the results of its calculations. The problem is to provide the computer with information at a speed which uses the tremendous speed of the computer. The units which provide the information and read the results obtained from the computer vary with the particular installation.

A program is written which describes the sequence of calculations which the machine is to perform. The problem data are collected and inserted into the computer which reads the program plus the data and stores this information. Having stored the necessary program and data, the computer is then started. After completing the series of calculations which it must perform, the computer produces the results which must be converted into indications (indicators or readable information).

The methods of providing the information for the computer varies with the requirements for the computed information. Mechanical changing information must be converted into digital language (analog to digital conversion). If the computed results are recorded on an indicating device, conversion from digital back to analog is necessary. Computer information will also come from units which prepare punched and magnetic tape and punched cards.

ANALOG TO DIGITAL CONVERSION

Figure 11-43 shows a block diagram of a servo loop that is used to produce a digital output in binary form from an analog unit. The analog input is applied to the comparator where it is chopped. The resultant a-c signal is then amplified and used to drive the servomotor. The servomotor shaft is coupled to the analog-digital coder (ADC) and a feedback potentiometer. The signal from the feedback potentiometer is fed back to the comparator. When the feedback equals the analog input, the servomotor stops driving. The ADC shaft is positioned to the value that represents the analog input.

The coding disk shown in figure 11-44 is a device that is used to convert a shaft position to binary coded digits. Assume that the dark areas are conductors and that the light areas are insulators.

The disk can be "read" by going in a straight line from the center of the disk to one of the numbers around the periphery. Read a 0 for each light area and a 1 for each dark area. Going from the center of the disk to the number one, we "read" 0001 which is the binary notation for decimal one. Going from the center to six, we get 0110, the binary notation for decimal six.

Assume that four electrical contacts (brushes) are placed above the disk so that each brush contacts one of the four concentric rings of the disk (2^0, 2^1, 2^2, 2^3). As the disk is rotated the brushes will come in contact with the dark areas as the dark areas pass under the brushes.

As the disk rotates under the brushes, a 1 (ON) signal is generated each time that a brush contacts a dark area, and a 0 (OFF) signal is generated each time a brush contacts a light area. The disk shown provides 16 positions, each of which consists of 4 binary digits (0000 to 1111). The 2^0 zone, which comprises the outermost ring of the pattern, consists of 16 alternating ON and OFF segments. These provide the last (least significant) binary digit of each word. The next ring toward the center, which comprises the 2^1 zone, provides the next least significant digit, etc.

Since only 4 zones are provided, the resolution of the disk is 1 part in 16. If an additional

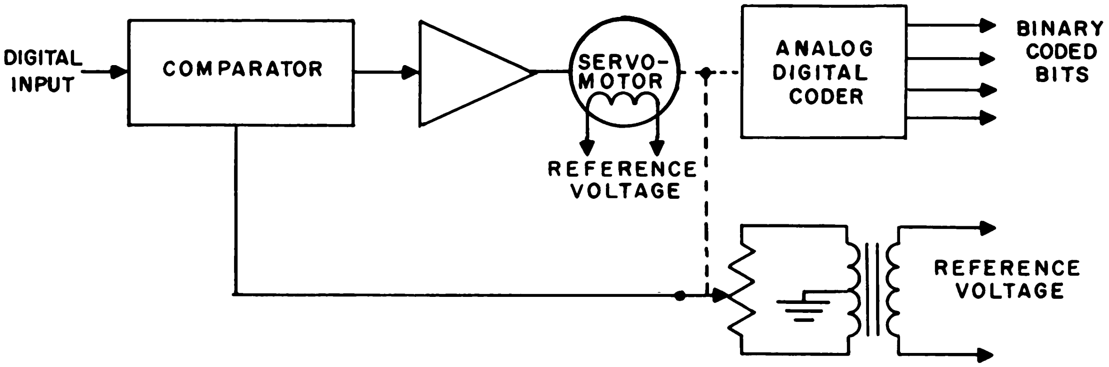


Figure 11-43.—Analog to digital servo loop.

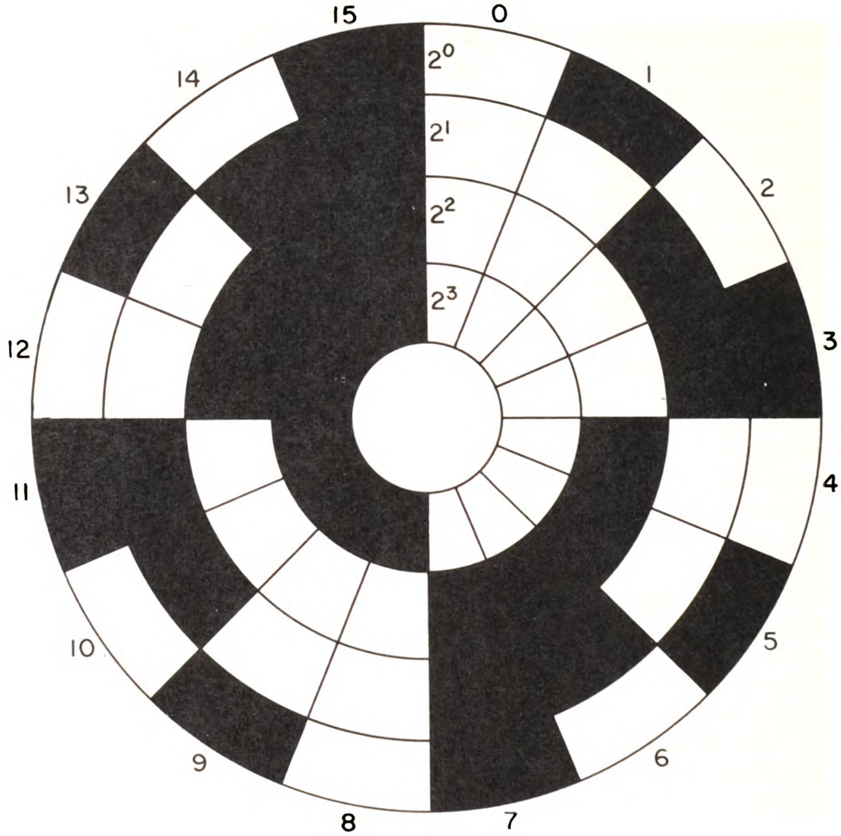


Figure 11-44.—The binary coded disk.

zone is added with 32 alternating ON and OFF areas, each of which is approximately one-half the size of the outer zone shown in figure 11-44, a resolution of 1 part in 32 will be obtained. The resolution can thus be increased by a factor of two for each additional zone that is added. Figure 11-45 shows a typical analog-digital coder with 4 coded disks.

DIGITAL TO ANALOG CONVERSION

Mechanical digital to analog conversion is almost always based upon feedback and comparison principles. A typical example is shown in figure 11-46. The digital input is fed into a comparator that serves as the input to a servo-amplifier and servomotor combination. The servomotor can be used to drive any of the many mechanical analog to digital converters. The digital output of the converter is fed back to the comparator, which operates as the servo error detector circuit. As long as the digital output does not equal the input, an error signal is developed. This signal continues to drive the servomotor. When the error signal is reduced to zero, the system stops. Then the shaft of the analog to digital converter provides a mechanical analog representation of the digital input. If a transducer such as a potentiometer is connected to the output shaft, it will provide an electrical signal that represents the same quantity.

The comparator shown in figure 11-46 could consist of the units shown in figure 11-47. Using this arrangement, the difference between the digital or binary input and the present position of the servomotor shaft is converted into an analog signal, which is applied to the servo-amplifier. Thus, when the analog shaft position corresponds to the digital or binary input, as indicated by the coded digits from the analog to digital converter, no further shaft rotation will occur, because the servoamplifier input signal is zero.

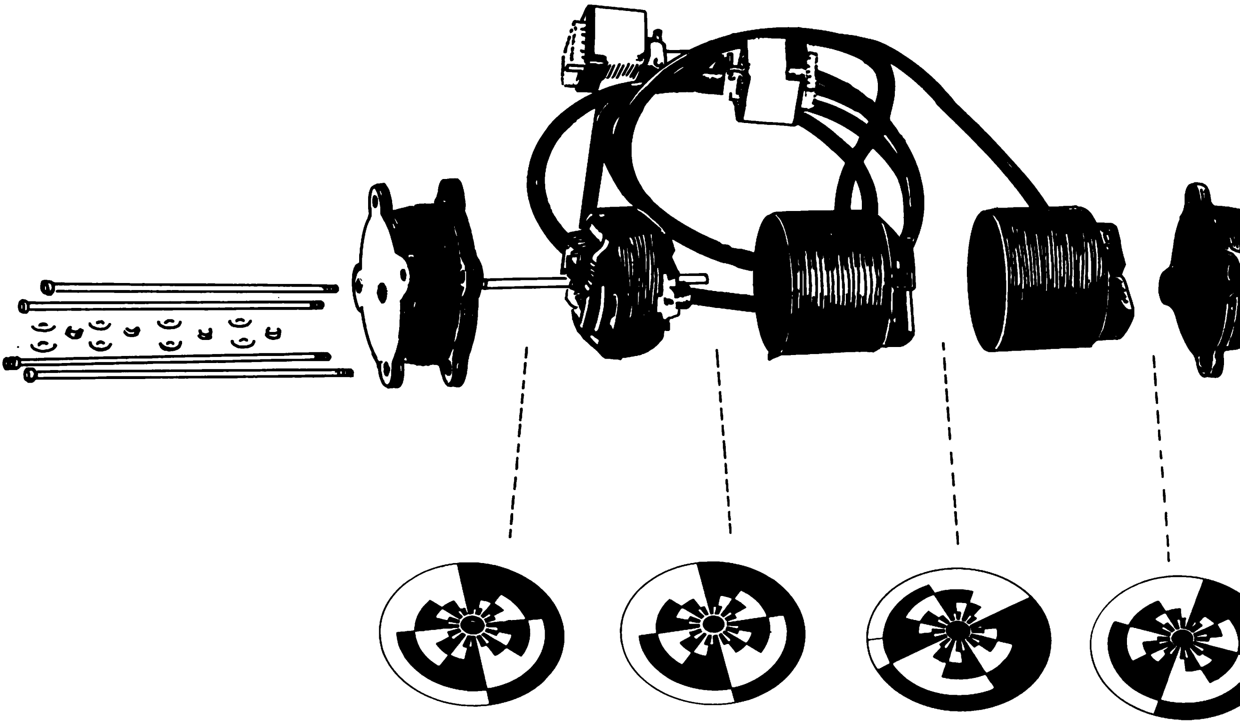


Figure 11-45.—Analog-digital converter.

TAPE

Perforated (punched) and magnetic tapes are among the popular mediums for storing the programs and data to be read into a digital computer. The punched tape has been used by telegraph systems for some years, hence the equipment for its preparation has been well developed. The punched tape, which is normally paper, varies in width from 0.5 to 3.0 inches. In general, the information is punched into tape (fig. 11-48) a line at a time. Multi channels are used (just as on magnetic ta a channel runs lengthwise along the tape), a fixed amount of information is punched a pattern of bits in each lateral line.

The preparation of these paper input ta is sometimes referred to as "keyboardin The operator of a tape punching machine cop the desired program and data by means o keyboard similar to a typewriter. The mach

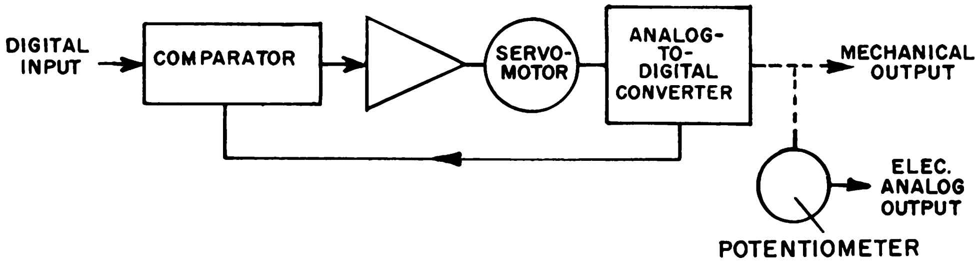
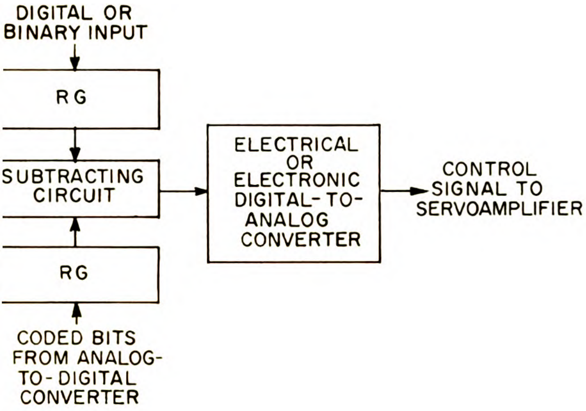


Figure 11-46.—Mechanical digital to analog converter.



igure 11-47.—Operational block diagram of the comparator.

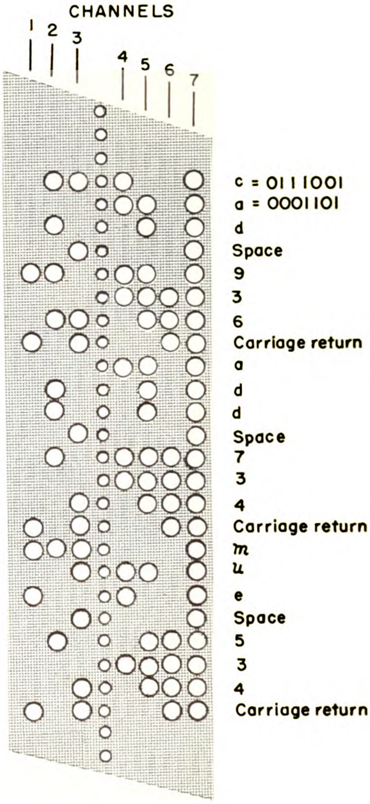


Figure 11-48.—Punched paper tape.

ınches the holes into the tape. The holes rep-esent, in coded form, the input information. punched hole in the tape is commonly used represent a 1, and the absence of a hole a 0. he small feed holes (fig. 11-48) are used to eep the tape alined as it passes through the eader.

Since digital computers operate using either nary or binary coded number systems, the input formation must include both numerical and phabetic characters. A code which contains oth letters and numbers is referred to as an pha-numeric code. Most alpha-numeric codes ontain additional symbols such as capital letters d punctuation marks. Code groups also use ıch operations as spacing, carriage return, c.

There are seven hole positions in each line the punched paper tape (fig. 11-48); however, ly six of these are used in the actual code. ne seventh hole is used to indicate whether not the information in each line is to be sed. If the seventh hole is punched, the tape eader reads that particular line of the tape d transmits the information in the line to the omputer. If the seventh hole is blank, the tape eader continues to move the tape until it en-ounters a punched hole in the seventh position.

A typical example of coding is as follows. ssume that the order code which causes the omputer to clear and add is CAD. In this case e card punch operator would punch the letters C, A, and D. The first line of the tape (fig. 11-48) then contains 011100, and the second 000110. This is followed by the address in storage to be added into the accumulator. The code for 2 is 001111 and the code for 3 is 000111. The data punched in this fashion is in the alpha-numeric coded form and must be further converted into binary coded or binary coded decimal words. A converted tape is coded in machine language and may be read directly into the computer and operated.

Magnetic tape is prepared in much the same manner as paper tape. The exception being that magnetic recording on the tape takes the place of the punched holes in the paper tape.

PUNCHED CARDS

A widely used input medium is the punched card. The size of the card varies with the particular use of the computed information. A typical card (fig. 11-49) is 3.25 in. by 7.75 in. This card provides 12 rows and 80 columns of information.

Just as with paper tape, the preparation of the card is with a card punching machine. The code used in punching the card (fig. 11-49) is the ''Hollerith'' code. It is an alpha-numeric code in which a single character is punched in a column of the card. As an example, the symbol A is coded by means of a punch in the top and 1 row of the card. The symbol 8 is punched in the 8 row of the card. Quite often the card punch machine prints the characters punched into the card on the face of the card itself. In this way, a card may be identified without examining the punches.

Most card readers are electromechanical units which convert the presence or absence of a hole into an electrical signal representing a binary 0 or 1. The cards are placed into a hopper. Upon starting, the bottom card is pulled first and is moved lengthwise over a row of 80 read brushes. These brushes read the information punched along the bottom row of the card. If a hole is punched in a particular row, a brush makes electrical contact through the hole in the card, providing a signal which is sent to the computer. The next row up is then read; this process continues until all rows have been read, after which the next card is moved into position on the brushes. Photocells are used in place of the brushes in some installations.

PROGRAMING

The digital computer does not figure out its own solution to a problem. It must be told exactly how to solve any given problem as well as how to make all decisions. The sequence of instructions which tells the computer how to solve a particular problem is called a program. The technique of preparing a program is called programing.

Data flow is the sequence of operations. The instructions to the computer are laid out a step at a time.

The program layout is the data flow prepared in reading form for insertion into the input unit. The instructions to the computer are prepared in two parts:

1. The ''operation code'' part which designates the operation (addition, subtraction, multiplication, etc.) to be performed.
2. The address of the number to be used.

A typical instruction word as written is: ADD 505. This means that the computer is to ADD; second, the address part 505 tells the computer the address in storage of the number to be used. The number 505 in the instruction shown is not the actual number to be added, but only tells the computer where to find the desired number. To what is the number at address 505 added? It is to be added to the number which is already in the arithmetic element. If the arithmetic element contains the number 100 before the instruction is performed, and the number stored at address 505 is 200, the number stored in the arithmetic element after the ADD operation will be 300.

A short program which adds three numbers together using the foregoing type of instructions is as follows:

Address in memory	Instruction word		Contents of arithmetic element after instruction is performed
	Operation code	Address part	
1	CLA	26	100
2	ADD	47	300
3	ADD	85	600
4	STO	39	600
5	HLT	0	600

The program operates as follows: the control section starts with the instruction word at address 1, which clears the arithmetic element and then adds (CLA) the number at address 26 into it. The instruction at address 2 adds (ADD) the number at address 47 to the number already in the arithmetic element. This produces the sum of 100 plus 200, or 300. The third instruction adds (ADD) the contents of address 85 to this sum, giving 600 in the arithmetic element. This number is then stored (STO) in memory at location 39 in the memory unit. The machine is then ordered to halt (HLT) at step 5.

Program coding is the transferring of the program layout containing the data flow of instructions into a form suitable for inserting into the computer. The input and output units discussed previously accomplish this job.

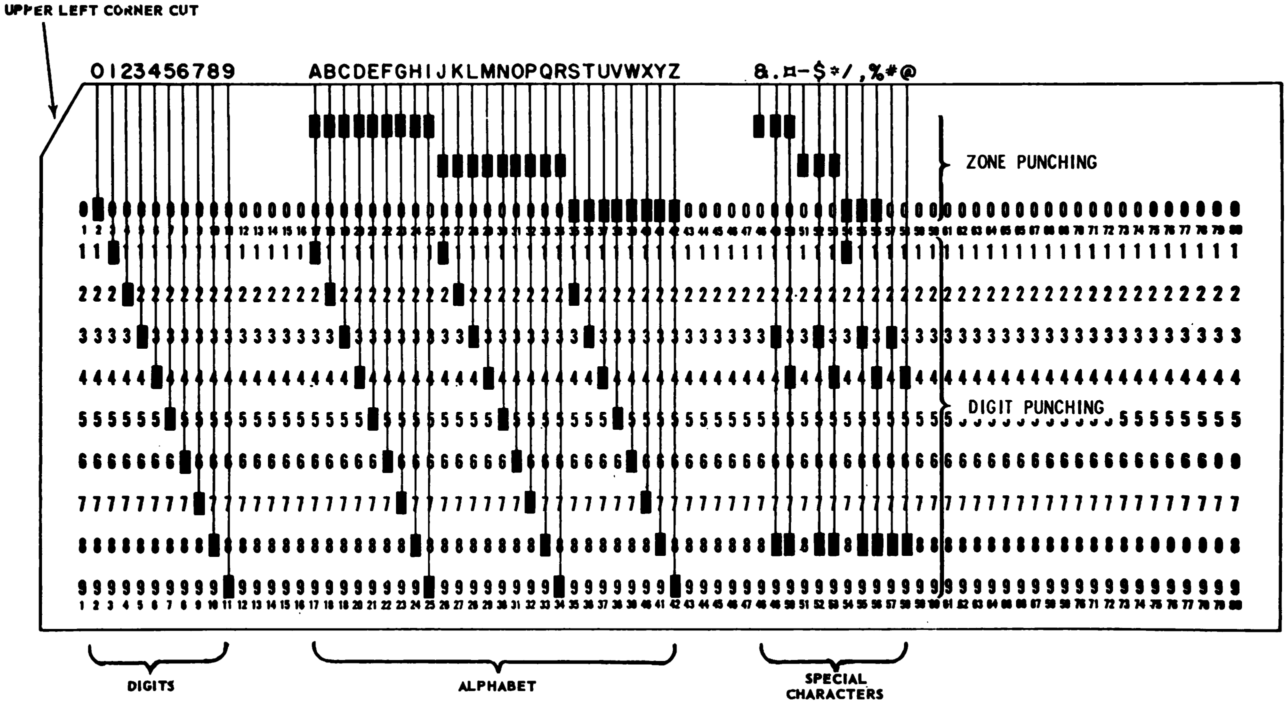


Figure 11-49.—Punched card.

CHAPTER 12

MAINTENANCE OF DIGITAL COMPUTER SYSTEMS

The digital computer circuitry, as described in the previous chapter, contains many interconnecting individual circuits. The maintenance of this type of equipment presents a formidable problem to maintenance personnel.

Most circuits found in computers are basic electronic circuits with which you should be familiar. The problem area is found to be the mathematical operations which require the changing of the interconnections between individual circuits. The differences between computers are the manners in which they achieve a solution.

One of the Tradevman's problems is to decide the validity of the answer of the computer. If the solution appears to be incorrect, the Tradevman must decide if the computer is functioning properly or if the program or programer is at fault. Since the computer will only process the information fed into it, an incorrect input will result in an incorrect output.

This chapter presents information on maintenance techniques that are applicable to all digital computers. It also discusses specific operational and training equipment and the correct maintenance techniques to be employed on the equipment.

COMPUTER DEMONSTRATOR

The digital Computer Demonstrator, device 6B4, is a classroom trainer used for explaining the theory and operation of basic logic elements. It also demonstrates the information flow and organization of a basic digital computer system. The functional subassemblies of a basic digital computer may be readily explained utilizing the demonstrator. Only the basic fundamentals can be demonstrated by the basic elements of the device.

The device 6B4 is a simple, small scale, general purpose digital computer using the techniques most representative of those used in large scale digital computers.

The device, shown in figure 12-1, consists of two units, the logic demonstrator/arithmetic unit and the command unit. The two front panels display a complete block diagram of the system from which the overall operation can be observed.

LOGIC DEMONSTRATOR/ ARITHMETIC UNIT

The logic demonstrator/arithmetic unit performs two functions. It is a logic demonstrator when the device is used to demonstrate the theory and operation of basic logic elements and the functional subassemblies of a basic digital computer system. It is also used as the arithmetic unit when the device is used as a functional computer system.

Logic Demonstrator

Conversion of the logic demonstrator/arithmetic unit for use as a logic demonstrator requires the removal of the front panel which exposes a panel of 53 D-PAC receptacles (fig. 12-2). Each receptacle can accommodate any type of D-PAC demonstration module and provides all the operating voltages required by the demonstration module.

The D-PAC logic demonstration modules are a compatible series of basic logic elements. When mounted in the D-PAC receptacles, they can be interconnected to demonstrate the theory and operation of the basic logic elements or functional subassemblies of a basic digital computer system. Special patchcords are used to connect the operation of the individual modules together.

Arithmetic Unit

When the device is used as a functional digital computer system, the arithmetic unit performs the mathematical functions of addition,

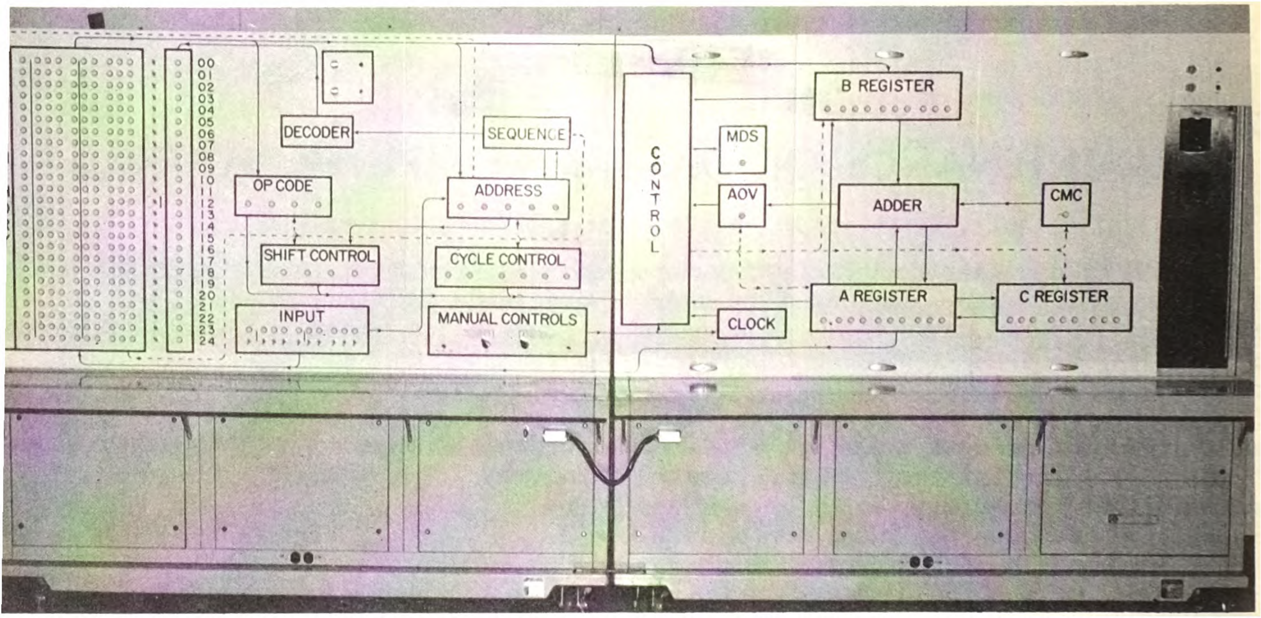


Figure 12-1.—Digital Computer Demonstrator, device 6B4.

btraction, multiplication, and division. The it consists of individual digital modules housed mounting racks. The front panels and mounting cks are accessible as each unit is mounted on slide-out assembly for ease of maintenance. complete block diagram of the arithmetic it is imprinted on the front panel of the monstrator. Incandescent indicators are used display the information stored in any of the ocks which represent register units.

OMMAND UNIT

The command unit performs the logic and narithmetic instructions when the device is ed as a functional computer system. In addition the control logic, the unit contains the memory d manual operating controls. The logic of the mmand unit uses 128 digital modules mounted 7 mounting panels. These units are mounted slide-out assemblies for ease of access. The ont panel of the command unit displays a com-ete block diagram of the unit. Incandescent dicators are used to display the information stored in the memory and all other important blocks.

POWER SUPPLIES

Each unit contains a power supply to provide the regulated voltages required by the digital and demonstration modules. The command unit contains an additional power supply to provide the required power to operate the front panel indicators on both of the units. Each unit is provided with a voltmeter and selector switch for monitoring the various voltages provided in the unit.

PLUG-IN CIRCUIT TESTER

A specially designed S-PAC tester is provided to test and troubleshoot the digital modules. The tester is designed to be mounted on any of the D-PAC receptacles. This allows testing of the digital module without having to remove it from the panel section. Details of the tester are discussed later in this chapter under maintenance.

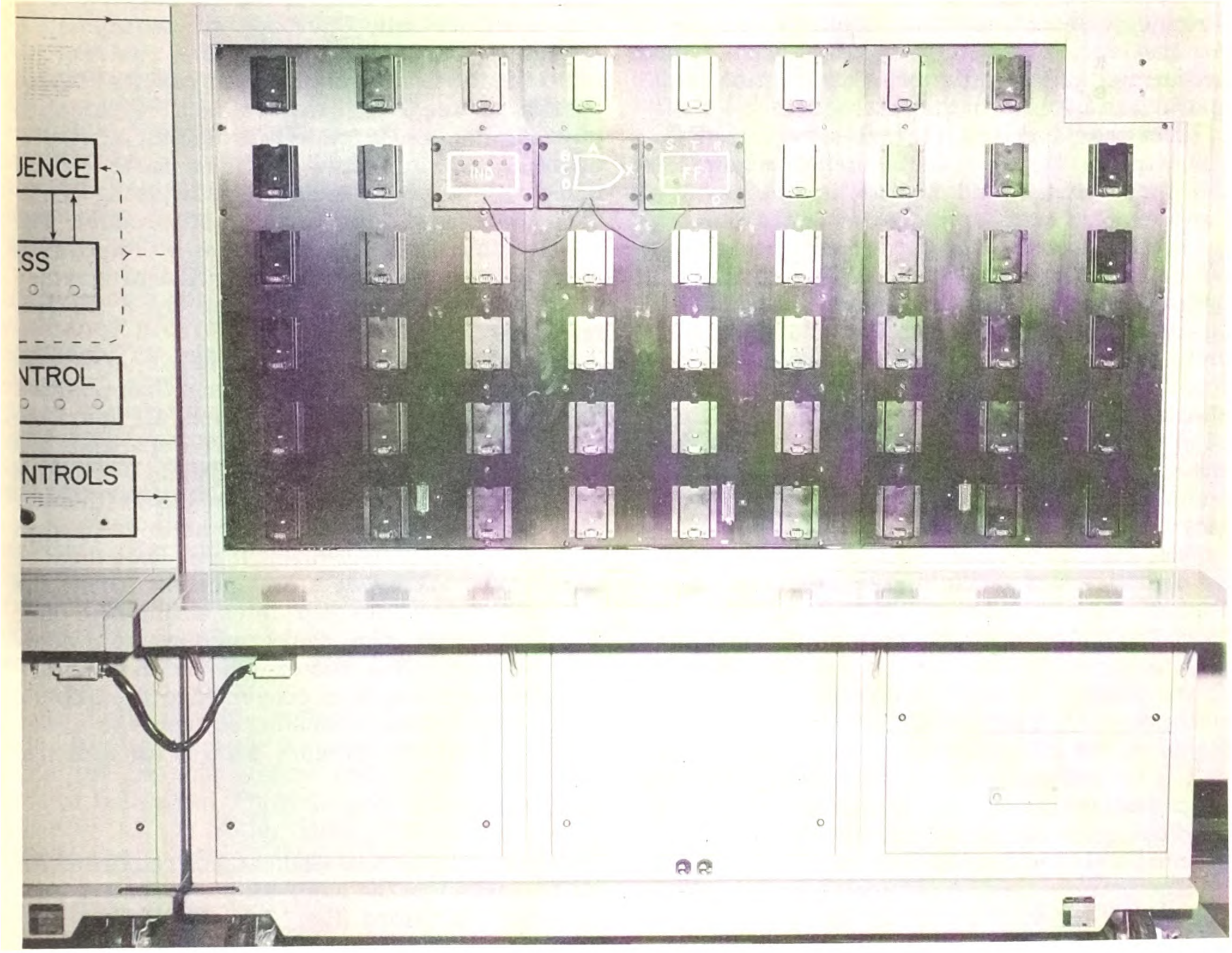


Figure 12-2.—Logic demonstrator, device 6B4.

COMPUTER OPERATION

As a computing system the device is a single-address, stored-program computer using a 10-bit instruction or data word. Thirteen instructions are available for programing the device. Normally, an entire program is executed without interruption each time the START push-button is pressed. However, the instructor can execute a single instruction, part of an instruction, or a single step in an instruction, and then stop the sequencing.

The memory section, which is an integral part of the command unit, stores the instructions and numbers (operands) to be used in a program of operation. The command unit interprets the instructions and directs the arithmetic unit to manipulate the operands in the manner directed by the instruction. The arithmetic result of this operation can then be stored in the memory. After a single instruction is completed, the command unit automatically obtains the next instruction from the memory section. In general, instructions are sequentially obtained from the memory section and individually executed by the command and arithmetic units.

The memory section is composed of 25 cells allocated addresses 00 through 24. One 10-bit word can be stored in each address. A word conveys two types of information; it is either a numerical quantity (an operand) or an instruction. Basically, there is no distinction between nstructions and operands in the memory section. The memory section holds only binary numbers. n instruction indicates the operation to be erformed and give the memory location of the perand to be used in the instruction.

The command unit interprets the instruction nd directs the arithmetic unit to manipulate he specified operand. The arithmetic result of he operation can then be stored in the memory.

Instructions do not refer to operands directly, ut refer to memory locations which contain the perating data. An instruction is said to be xecuted when the operation it orders is comleted. As stated before, the device cannot disinguish between instruction and operand words tored in the memory section. The interpretation f a word depends on the context in which it is sed. This is specified when the program is ompiled. In some programs, the instructions ay be used as operands.

The display provided by the memory indicaor lights serves as the represented output of the evice. Intermediate or final results can be tored in the memory and read out on the indicaors. A toggle switch controls each memory adress which allows the indicator lamp for that ddress to be disabled. Only the indicators are isabled; the information stored in the memory ell is not destroyed since the memory provides nondestructive readout. After information is ead out, information is retained in the addressed emory cell and displayed on the indicator lamp.

The command unit synchronizes and monitors ll operations in the device. To perform these unctions, the command unit extracts instrucions from the memory and interprets them to erive control signals. Control signals are derived by decoding the instructions within the ommand unit. Each instruction is decoded into specific series of control signals that direct he command and arithmetic units to perform all f the operations required by the instruction. The control signals extract the information (the operand) from the memory location specified y the instruction, and transmits the information o the arithmetic unit. Additional control signals irect the arithmetic unit to manipulate the he operands in the manner ordered by the nstruction. If special conditions arise in the ourse of manipulating the operands, the command unit can issue additional control signals to ope with the change in operation required by he special conditions.

The arithmetic unit manipulates operands, which are supplied from the memory section, and is directed by control signals supplied from the command unit. Operands are manipulated, or processed, to perform addition, subtraction, multiplication, and division. The results of these operations are 9-bit numbers, with the exception of multiplication. Products formed during multiplication are in double precision form (18-bit numbers), since the result of multiplying one 9-bit number by another is an 18-bit product. The result of any arithmetic operation is temporarily stored in the arithmetic unit until a programed delivery to memory is order by a STORE instruction.

In the arithmetic unit, negative operands usually appear in a different form than positive operands. In the memory section, all operands are in the absolute value. Negative operands are distinguished from positive operands by the sign bit (the tenth bit). However, in the arithmetic unit, negative operands are sometimes used in the two's complement form. If a number must be converted to the two's complement form, the conversion is performed in the arithmetic unit. The number is then manipulated in two's complement form. If a result appears in the two's complement form, it is converted to the absolute value before being transferred from the arithmetic unit to the memory section for storage.

MAINTENANCE

The controls and indicators required for maintenance are the same as the operating controls and indicators (fig. 12-1). In addition to the normal controls, a pushbutton called MAINTENANCE START is provided inside the device cabinet. This pushbutton provides facilities for initiating a computer program from the rear of the equipment.

Preventive

The following procedures should be performed periodically and prior to using the device for demonstrations:

1. Check the primary power and power supplies by performing the installation and checkout procedures given in the device's maintenance manual. If the primary source power is not within the specified limits, the public works department should be contacted for repairs. If the power supply voltages are not within the specified limits consult the maintenance manual for the correct adjustment procedures.

2. Preventive maintenance of the cooling unit requires the replacement of the disposable filter once a month. The operation of the cooler is checked by placing the line power switch to ON and observing the cooling unit power indicator which should be glowing. If the indicator is not glowing, check the fuse for the cooling unit. If after replacing the fuse, the indicator glows, check the three fans of the cooling unit for proper operation.

3. The maintenance manual contains operating tables for checking the computer's performance programing. This program exercises the logic circuitry contained in the device. The program should be run for at least 5 minutes prior to using the device. When the equipment is operating normally the program will recycle indefinitely. However, if a malfunction occurs, the test program will stop.

4. Keep the device clean and free from oil or solvents. Exterior and interior surfaces should be cleaned periodically. Use a soft, damp, lint-free cloth to clean the exterior surface. Remove dust and foreign matter from the interior of the equipment by using a soft brush or vacuum cleaner.

5. Lubricate the roller guides on the units periodically. Remove the dust and foreign matter from the top and bottom roller guides on each side of both units. Apply the prescribed lubricant directly to the roller guides. This procedure should be performed once every 3 months.

Troubleshooting

The prime prerequisites for maintaining an optimum operating status of the device are a detailed knowledge of the equipment's theory of operation and an ability to use the logic and schematic diagrams contained in the maintenance manual. Of equal importance is the ability of using wiring lists (a list of wires and their connections) and logic equations (in lieu of logic diagrams) for maintenance. With these assets the TD can quickly evaluate suspected failures and isolate a trouble to a small group of modules, and then to an individual module.

When the results of specific program operations are known to be in error, the recommended procedure for isolation of the failure is to rerun the program in the single instruction mode to determine which particular instruction is responsible for the error. Use of the single cycle mode of operation allows the error to be localized to a functional section of the computer by comparing calculated results with indicated results. Analysis of the appropriate logic diagrams with the symptoms established by program operation will enable isolation of the failure to one or more removable modules. When a failure is isolated to a specific area of a functional section, maintenance should be confined to replacing defective PAC digital modules with known reliable spares to permit the system to continue operation while the defective module is being repaired.

When a failure is suspected in the device, detect and isolate it by performing the overall and functional section procedures described in the maintenance manual.

After the faulty module has been replaced, the TD proceeds to repair the unit. The module (fig. 12-3) is a sandwiched unit with printed circuit board connections and wiring. The components are mounted on one side and the wiring on the other side. The unit is formed like a sandwich and makes removal easy with the board connections sliding into connectors in the mounting rack. Open construction allows maximum ventilation which promotes stable operation.

The power amplifier module (fig. 12-3) contains four individual circuits. An individual circuit is shown schematically in figure 12-4. Examination of figure 12-3 shows that the components of each circuit are grouped to form a cluster or section, and that the module is divided into four sections.

Each power amplifier circuit has one d-c input and two d-c outputs. The single input may be coming from as many as 10 circuits.

When the input is zero, only one transistor (Q4) is conducting. This transistor clamps both outputs through isolating diodes CR8 and CR9 to a -6 volt level. Electron flow is from the -18 volt source through R1 and CR1. Three additional paths for electron flow are as follows:

1. R1, R3, and R8 to the +12 volt source.
2. R1, R4, CR2, and R7 to the +12 volt source.
3. R1, R5, CR3, and R6 to the +12 volt source.

Electrons flowing through the three paths place a positive voltage on the bases of transistors Q1, Q2, and Q3, which cuts them off. Electron flow occurs from the -18 volt source through R2, Q4, CR8, and CR9 to the cathodes of CR4 and CR6. A -6 volt appearing at the base of Q4 causes electron flow and places the -6 volt potential at outputs A and B.

When the input is binary 1 (-6 volts), the gate transistor Q1 turns the two output transistors Q2 and Q3 on and each output is clamped through

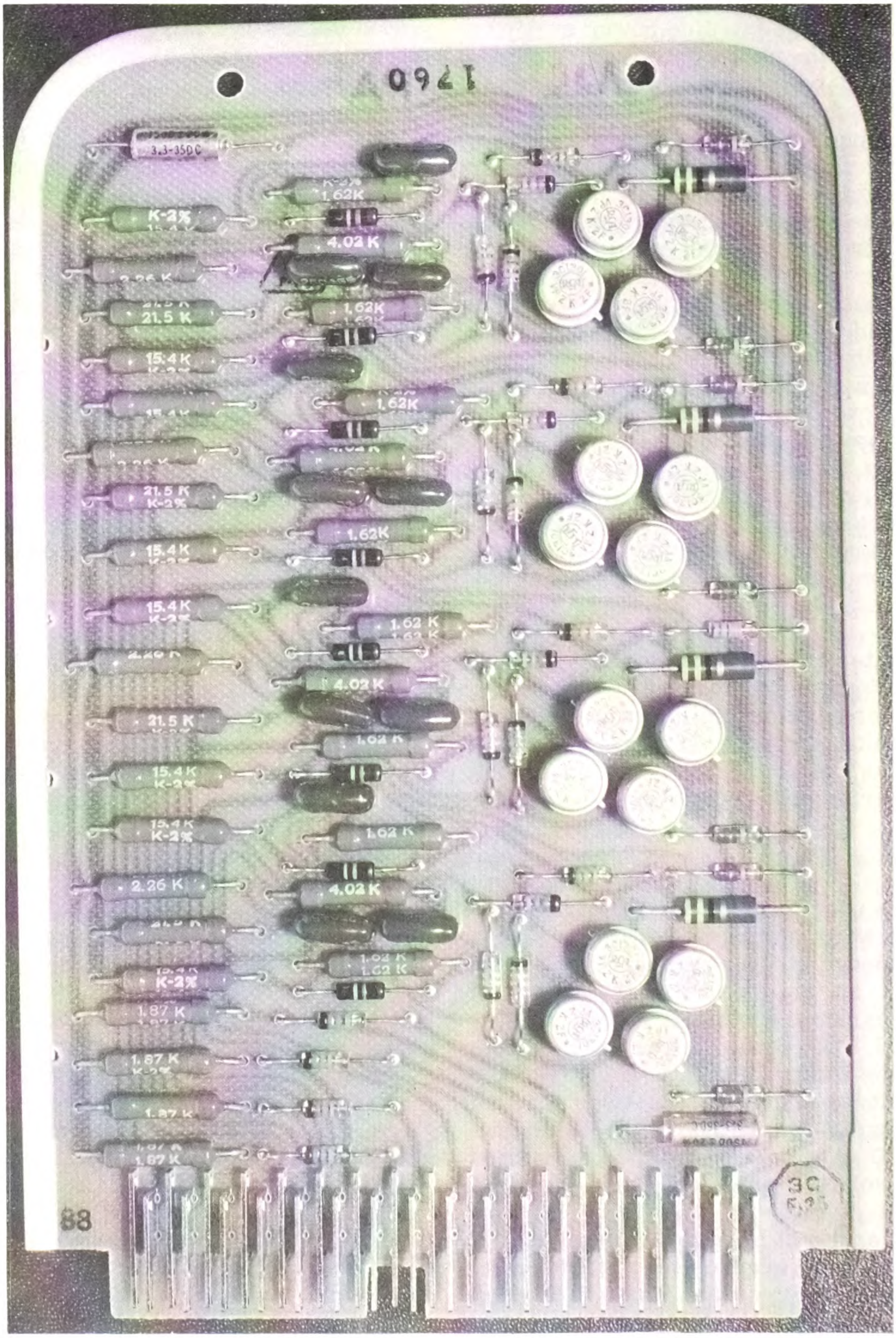


Figure 12-3.—Power amplifier module.

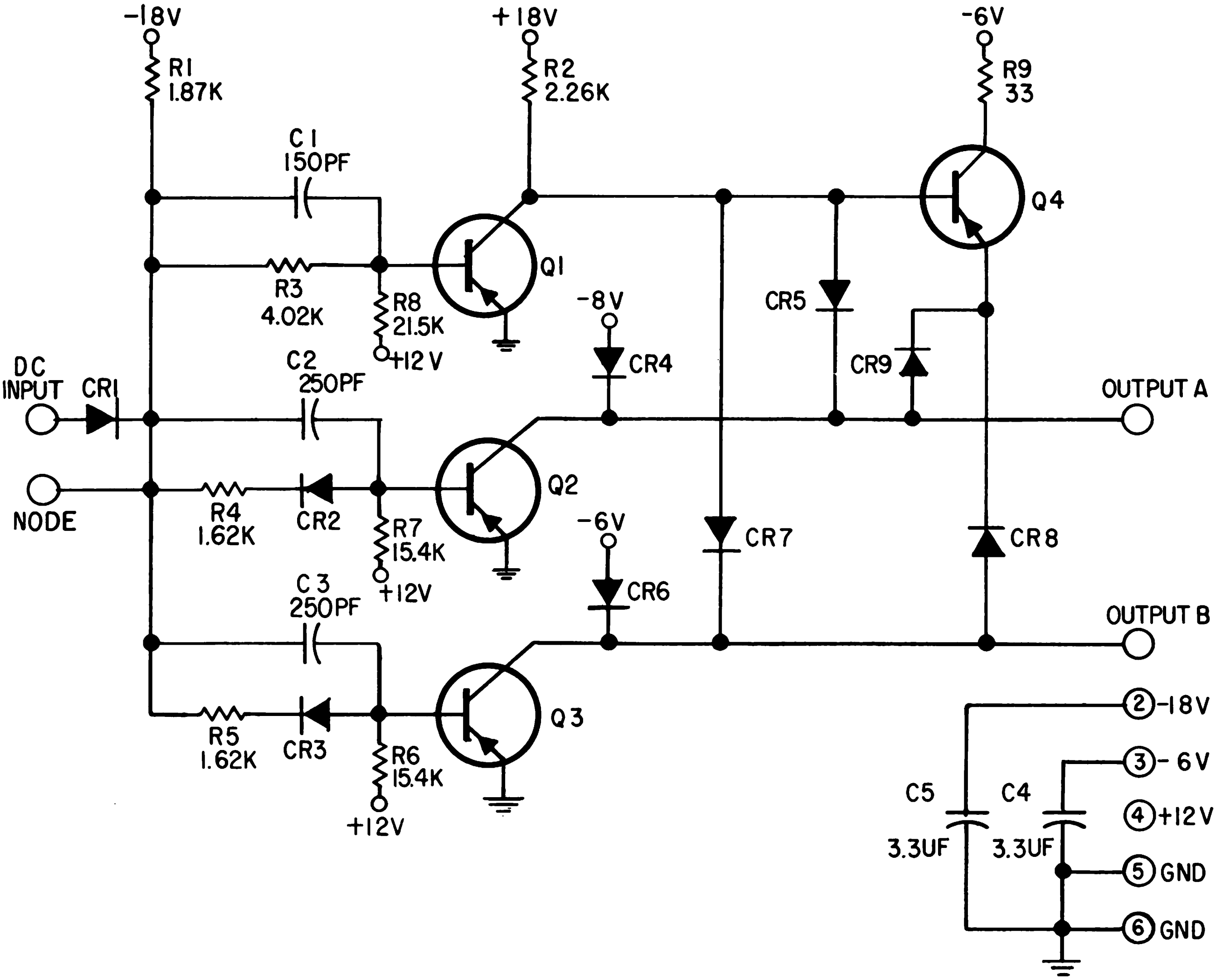


Figure 12-4.—Power amplifier circuit.

Q4 at zero output. The -6 volts at the input causes more electron current through R8, R7, and R6 causing the bases of the transistors to be more negative and allowing them to start conducting. Electron flow through Q1 causes the base voltage of Q4 to be approximately zero, reducing electron flow through CR8 and CR9. Transistors Q2 and Q3 are conducting, placing zero voltage at the collectors which are connected to outputs A and B.

The PAC tester (fig. 12-5) is designed to assist in the isolation of a faulty component in a module. It provides a means of mounting a faulty module and permits access to all of its components. All operating voltages are supplied through the tester and are connected to jacks on the front panel. The jacks facilitate the inserting of a meter/scope for testing the circuitry and components on the module. Jack pin No. 5 is provided for the ground connection of the test equipment. A negative 14-volt output jack, a lamp input jack, and an incandescent lamp are also provided for test purposes. A swing-away holder holds the printed circuit board when inserting it into the connector block.

Replacing of components on the printed circuit board is discussed later in this chapter.

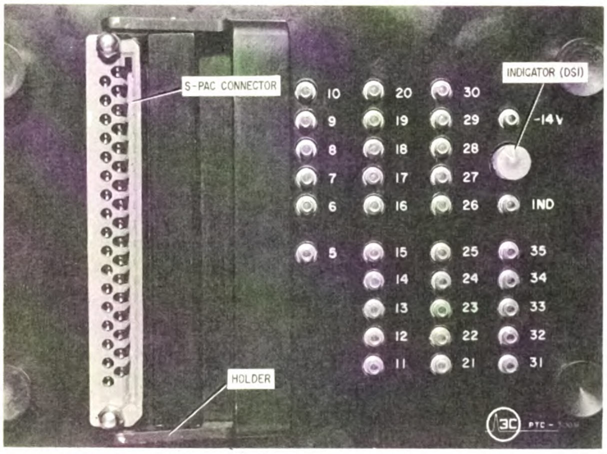


Figure 12-5.—PAC Tester.

TRADAC DEMONSTRATOR

The TRADAC (Training Automatic Digital Computer) demonstrator is a general purpose computer. The principle of operation and the technique of programing, while very basic, afford a simple explanation of troubleshooting a computer by analyzing its sequence of operation. The machine is a single-address, stored-program computer capable of carrying out a variety of different operations.

The memory unit is a drum type and contains 128-word addresses (0 through 127). Eight channels contain 16 words per channel. Ten significant digits per word, plus a sign bit, and one space between each word make up one complete word.

The arithmetic unit consists of a one-word accumulator. Also contained in the arithmetic unit is the adder/subtractor and multiplier/divider.

The input and output units may be tapes, punched cards, or automatic printers.

The control unit, containing two recirculating registers, is located on the same drum as the memory unit. The next instruction ("N" register) holds the address of the next instruction to be carried out by the program. The address register ("A" register) holds the address of the operand (quantity) to be read from memory. The operand is any one of the quantities entering into, or arising from, an operation. A sector identification (ID) channel contains a permanent record of the sector number of the words in the memory unit. This provides the means by which each of the 16 words per channel is identified.

A clock pulse channel provides timing pulses for synchronizing the computer's operation. Synchronization is further maintained by a reference mark channel. This channel contains one pulse used to synchronize the one-bit counter.

INSTRUCTIONS

The computer can obey eight different instructions. Each memory address (one memory cell or word) may hold either a number to be operated on by the machine, or an instruction. An instruction is part of a computer word. It contains the instruction or operation to be carried out and the address of the number of data upon which the instruction is to operate.

The operation carried out by each of the eight instruction words are as follows:

1. ADD (A): Extract the number from memory location "N" (data address) and add it to the number in the accumulator, leaving the result in the accumulator. A-92 means to add the number in memory address 92 to the contents of the accumulator. This instruction does not modify either the instruction address or the data address, only the contents of the accumulator are modified.

2. SUBTRACT (S): Subtract the number in memory location "N" from the number in the accumulator and leave the result in the accumulator. S-76 means subtract the number in memroy address 76 from the contents of the accumulator. As with the add instruction, only the contents of the accumulator are modified.

3. TRANSFER (T): Transfer the number in the accumulator to memory location "N" where it will replace the number previously in that memory location. T-102 means to extract the number in the accumulator and place it in memory location 102. This instruction does not modify the contents of the accumulator or the instruction address, but does modify the contents of the memory location "N."

4. TRANSFER CLEAR (TC): Transfer the number in the accumulator to memory location "N," replacing the number there. At the same time store the number zero in the accumulator. TC-127 means transfer the data in the accumulator to memory location 127 and write zeros into the accumulator. This instruction modifies

the contents of the accumulator and memory location "N."

5. DIVIDE (D): Divide the number in the accumulator by the number in memory location "N." Only the contents of the accumulator will change.

6. MULTIPLY (M): Multiply the number in the accumulator by the number in memory location "N." Only the contents of the accumulator will change.

7. COPY IN (CI): Copy or read what is to come in and place it in the accumulator. If a tape input is used, the instruction will also advance the tape to be ready to read the next bit of information.

8. COPY OUT STOP (COS): Feed the data in the accumulator to the output unit and stop the machine.

PROGRAM PREPARATION

The maintenance of a computer begins by analyzing the operation of the computer. A program written for the purpose of checking the correct sequencing of the computer will evaluate the computer's accuracy. The program will present the computer with a problem whose answer has already been correctly determined. If the computer produces the wrong answer, the malfunction can be diagnosed by evaluating the answer.

In writing a program for a computer, it is necessary for the programer to utilize the instructions that the machine is capable of obeying. In the case of the program (table 12-1), the problem to be placed into the computer is $\frac{2Y-Z+3X}{5}$. It is necessary for the programer to place the constants (2, 3, and 5) and the variable (X, Y, and Z) in known memory locations. According to table 12-1 these quantities are assigned to memory locations 18 through 23.

The next step in the preparation of the program is to prepare in sequential form the steps required for the computer to solve the problem. The program (table 12-1) illustrates the sequential program as location steps 8 through 17. The binary numbers for the steps appear beside the numerical ((8) 000-1000).

The column marked INSTRUCTION shows the written instruction. The next column marked INSTRUCTION WORD shows the written instruction in binary language. The instruction TC-127 changes to the instruction word 0-011-111-1111. As can be seen from table 12-1, the binary 011 is the translated instruction for TC (transfer clear); the number 127 is memory location 127 which in binary is channel 7 (111) and sector 15 (1111).

Initial Input Routine

The entire action of the computer, including the operations of input and output, takes place under the control of a program of orders placed in memory. Once the input routine is started, the action of the computer can continue indefinitely. In order to start the action, it is necessary to have a means of placing the input routine into the machine. This is accomplished by the use of a uniselector switch similar to a rotary telephone switch. The input routine is prewired on this switch. As the uniselector rotates, the input routine instructions are sequentially placed in the memory unit with the first order in the memory's first location.

The input routine uses steps 0 through 7 as follows:

Step 0 - (TC-127): This instruction is placed in memory location 0 by the uniselector switch. Step 0 is used to clear the accumulator.

Step 1 - (CI): This instruction is placed in memory location 1. This step will read what is on the tape, store it in the accumulator, and advance the tape.

Step 2 - (T-8): This step stored in memory location 2 transfers the first bit of information to memory location 8, and also leaves it in the accumulator.

Step 3 - (A-126): Memory location 3 holds this instruction. A binary 1 is also placed in location 126 which is added to what is in the accumulator. The adding of one-bit is used to see if the information read from the tape is the last step of the program being fed into the computer.

Step 4 - (TC-127): This step is placed in memory location 4 and is used to clear the accumulator.

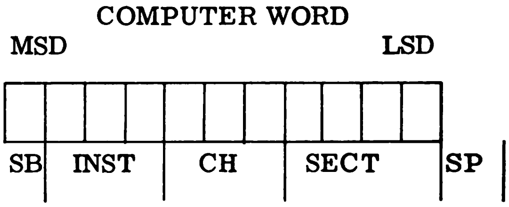
Step 5 - (A-2): This instruction is placed in memory location 5 and totals the contents of memory location 2 into the accumulator. In this case the instruction T-8 is in memory location 2.

Step 6 - (A-126): This step, placed in location 6, adds a 1 to what is in the accumulator. In this case the 1 is added to the T-8 in the accumulator and it comes out as T-9 in the accumulator.

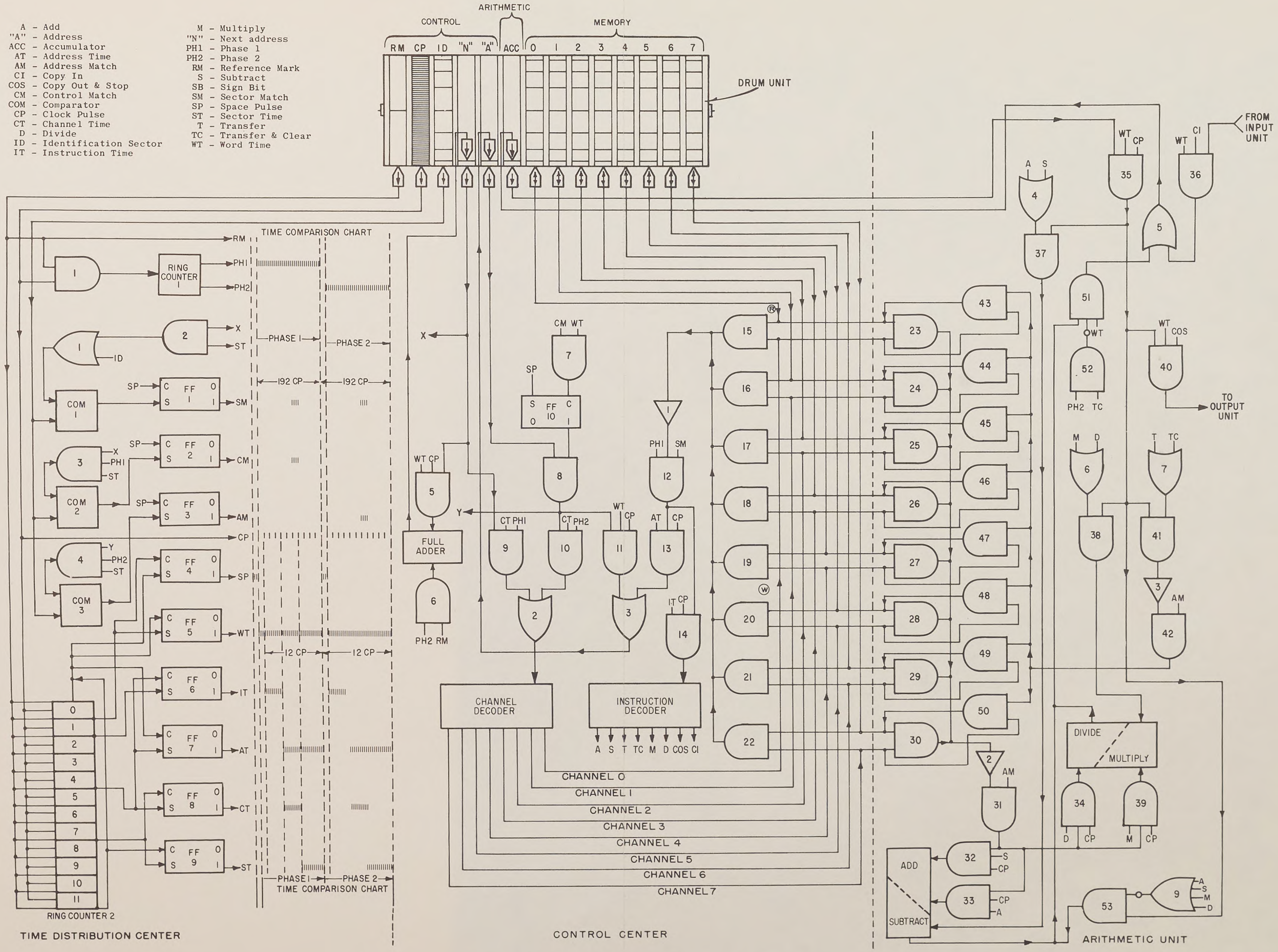
Table 12-1.—Digital computer program.

Problem: $\frac{2Y-Z+3X}{5}$

ADD - 000
SUB - 001
T - 010
TC - 011
D - 100
M - 101
COS - 110
CI - 111



MEMORY LOCATION N-REGISTER	INSTRUCTION	INSTRUCTION WORD	REMARKS
(8) 000-1000	TC-127	0-011-111-1111	Transfers contents of Acc. to loc 127 and clears Acc.
(9) 000-1001	A-19	0-000-001-0011	Y is added into Acc.
(10) 000-1010	M-21	0-101-001-0101	Takes 2 times Y in Acc.
(11) 000-1011	S-20	0-001-001-0100	Subts Z from what is in Acc. (2Y-Z)
(12) 000-1100	TC-126	0-011-111-1110	Transfers contents of Acc. to loc 126 and clears Acc.
(13) 000-1101	A-18	0-000-001-0010	X is added into Acc.
(14) 000-1110	M-22	0-101-001-0110	Takes 3 times X in Acc. (3X)
(15) 000-1111	A-126	0-000-111-1110	Adds contents of loc 126 to what is in Acc. (2Y-Z+3X)
(16) 001-000	D-23	0-100-001-0111	Divides contents of Acc. by contents of loc 23. $\frac{2Y-Z+3X}{5}$
(17) 001-0001	COS	0-110-000-0000	Copy, out, stop.
(18) 001-0010	-	X	This location contains the variable X.
(19) 001-0011	-	Y	This location contains the variable Y.
(20) 001-0100	-	Z	This location contains the variable Z.
(21) 001-0101	-	2	This location contains the constant 2.
(22) 001-0110	-	3	This location contains the constant 3.
(23) 001-0111	-	5	This location contains the constant 5.
(126) 111-1110	-	-	Temporary storage.
(127) 111-1111	-	-	Rubbish.



A - Add
"A" - Address
ACC - Accumulator
AT - Address Time
AM - Address Match
CI - Copy In
COS - Copy Out & Stop
CM - Control Match
COM - Comparator
CP - Clock Pulse
CT - Channel Time
D - Divide
ID - Identification Sector
IT - Instruction Time

M - Multiply
"N" - Next address
PH1 - Phase 1
PH2 - Phase 2
RM - Reference Mark
S - Subtract
SB - Sign Bit
SM - Sector Match
SP - Space Pulse
ST - Sector Time
T - Transfer
TC - Transfer & Clear
WT - Word Time

Figure 12-6.—TRADAC demonstrator block diagram.

Step 7 - (T-2) This instruction is placed in memory location 7. The step takes the T-9 now in the accumulator and transfers it to memory location 2. Since the first bit of information read from the tape went into location 8 (table 12-1), it is logical that the next bit goes into location 9.

The address specified by the number in location 2 is changed by 1 every time the input routine is exercised until all of the information is read from the tape. The last bit of information read from the tape is a series of 1's that produces an overflow and sets a flip-flop that opens an AND gate allowing the "N" register to advance its count past step 7.

After all the information is read from the tape, the computer advances to memory location 8 and starts the program (table 12-1) that has been read into the computer. Upon completing the program the computer will stop.

PROGRAM OPERATION

Figure 12-6 is a block diagram of the TRADAC demonstrator. It includes the various circuits, the magnetic drum, and a time comparison chart. Refer to the figure as necessary throughout the following discussion.

The magnetic drum contains 8 memory channels numbered 0 through 7. Each channel contains 16 words, hence a memory capacity of 8 x 16 = 128 word addresses from 0 through 127. Each computer word consists of 11 bits plus a space pulse. Referring to table 12-1 it can be seen that the computer word consists of one sign bit (SB), 3 instructions bits (INST), 3 channel bits (CH), and 4 sector bits (SECT) and 1 space pulse (SP). The memory location is identified by channel and sector. A memory address of 127 would be 7 bits long and shown in binary form as 111-1111 (binary 127). The memory location would be in channel 7 (111) and sector 15 (1111).

Time distribution is of prime importance to assure that all phases of operation of the computer occur in proper sequence. The time comparison chart (fig. 12-6) illustrates the various timing pulses occurring within the computer. Where time is measured in microseconds, timing is of the utmost importance. From the time comparison chart it can be seen that varying lengths of time intervals occur. For example, word time (WT) is 11 bits; this is as long as channel time (CT), sector time (ST), instruction time (IT), and sign bit (SB) combined. Address time (AT) is as long as both channel time and sector time.

The source of the timing pulses is a channel on the drum called the clock pulse (CP). As the drum rotates, pulses are continually sent to the various circuits which provide a synchronizing action so the action of the circuits start and stop at the proper time.

Timing is also controlled by the reference mark (RM) portion of the drum. A single pulse mark on the drum produces a pulse each time the drum rotates by its reading head. When the single pulse mark passes the reading head for the first time, a pulse is sent to AND 1 and then to the ring counter which is set for phase 1 operation. Phase 1 (PH1) operation is the time when the instruction is being read from memory into the computer control. This is telling the computer whether to add, subtract, transfer, etc. The drum is completing one complete revolution during this instruction time. When the reference mark passes the reading head for the second time, the pulse through AND 1 to the ring counter switches operation to phase 2 (PH2).

A ring counter is a circuit whose input pulses cause an output pulse to step from one output lead to the next, and then return to the starting point. The AND 1 circuit provides an output only when the reference mark (RM) and the clock pulse (CP) occur at the same time.

By observing the time comparison chart, it can be seen that in the following sequence of operation the control circuits are providing pulses in sequence which step the computer circuits through the program. It should be noted that the lower section of the chart represents 12 clock pulses (CP) while the upper half represents 192 clock pulses and is one complete revolution of the drum.

In the original condition prior to starting the computer, flip-flop FF4 is in the set condition, so the space pulse (SP) is one. FF5 through FF9 are in the clear condition, producing an output of 0.

NOTE: On the time comparison chart, an output pulse is present for the space pulse and no pulses are present for word time, instruction time, channel time, and sector time.

After the first clock pulse appears through ring counter 2, FF4 flips to clear, thus reducing the output of the space pulse to zero. This same pulse sets FF5 causing an output of word time to start. The one pulse width (between CP1 and CP2) represents the sign bit (SB); in the example program (table 12-1) the sign bit is 0, hence no output pulse.

The second output of ring counter 2 sets FF6 starting instruction time for three clock pulses. At the end of four clock pulses, the third output of ring counter 2 occurs. This pulse sets FF7 and FF8, and clears FF6 which starts address time and channel time and stops instruction time.

At the end of seven clock pulses, the fourth output from the ring counter is produced. This sets FF9 starting sector time and stops clock time.

The last clock pulse produces the fifth output from ring counter 2. This will cause FF4 to go to the set condition producing the space pulse in preparation for the next phase. Ring counter 2 returns to its starting position, which is step 0 and clears FF9, FF7, and FF5. The control circuit is in position to start the next word.

Other output pulses shown in the top section of the time comparison chart (fig. 12-6) include sector match (SM). An output pulse of sector match is produced as an output from FF1. It is produced when the sector from the identification sector channel and the sector from the "N" register coincide when compared in COM 1. The inputs to AND 2 are the information contained on the "N" register and sector time. The output from AND 2 will be only the pulses that pertains to sector information. A sector match pulse, one word long, is produced for every revolution of the drum. It is used to complete circuits allowing information to flow to the control section during phase one. FF1 clears when the space pulse occurs at the beginning of the next phase of operation.

Control match (CM) is the output pulse of FF2. It is produced under the same conditions as sector match except that the pulse is produced only during the phase one revolution of the drum. The input to FF2 is from COM2. The pulse is used to prevent recirculation of old material on the "A" register when new material is being inserted into the machine. FF2 is cleared by the space pulse occurring at the start of phase 2.

The address match (AM) is used to complete circuits allowing information to flow out of memory to the arithmetic unit or into memory from the accumulator. An address match pulse is produced as an output of FF3 during phase 2. It is produced when the sector information from the "A" register is compared with the sector information on the identification channel in COM 3. The space pulse occurring at the start of phase 1 clears FF3.

Reading in the Next Instruction

As previously noted each instruction is carried out in two parts. During the first part, the instruction is read from memory into the control unit where it can be identified; during the second part, the instruction just read is performed. The following discussion shows how the first part is accomplished. The sequence is the same for all instructions.

Assume that the program (table 12-1) has been loaded into the computer. Under these conditions the address of the next instruction is binary eight (memory location eight). The first instruction is TC-127 which is a transfer and clear instruction. It should be remembered that this means to transfer the number in the accumulator to memory address 127 and write zeros in the accumulator.

The instruction TC-127 is accomplished in the computer by first making a memory search for the word whose address is in the "N" register. The instruction withdraws this word from memory, and decodes and stores it where it can be referred to (in the "A" register and instruction decoder) later on.

Assuming that binary number eight is coming from the "N" register via its reading head, the number is routed to the input of AND 2. Sector time, also at the input of AND 2, allows an output from AND 2 to go to OR 1 where the pulses pass on to the input of COM 1. If a pulse other than binary eight is coming from the identification sector channel, there will be no output from COM 1. The number from the "N" register recirculates and continues to come up until a match occurs. When the identification sector reading head sends binary eight to COM 1, a match occurs producing an output to FF1. FF1 reverts to a set condition producing a sector match pulse to AND 12. At the same time the number from the "N" register is going to AND 9.

The AND 9 circuit passes only those pulses which correspond to the proper channel. Operating in phase 1 and receiving channel time and "N", the pulses pass through AND 9 to OR 2. The pulses pass through OR 2 and into the channel decoder. The channel is decoded as channel 0 since memory location 8 is in this channel (the 0 channel holds locations 0 through 15).

From the channel decoder, the pulses depart on the channel 0 line and are connected to AND 15, AND 23, and AND 43.

With inputs to AND 15 from channel 0 of the decoder and a pulse from the reading head of channel 0, an output pulse goes through AMPLIFIER 1 to AND 12. AND 12 is already receiving a phase 1 and sector match pulse; consequently, AND 12 passes the pulses. The pulses passing through AND 12 is the binary number representing TC-127. The instruction portion of the number is routed down through AND 14 into the instruction decoder to become transfer and clear (TC).

The address portion of the number (127) from AND 12 is routed down through AND 13, OR 3, and into the writing head of the "A" register. Notice that AND 14 passed only the instruction portion because it was controlled by the input instruction time which provided pulses only during the instruction time portion of the time comparison chart.

At the same time the above sequence is occurring, the number from the "N" register is routed through AND 3 into COM 2. The corresponding number from the identification sector drum is also at the input of COM 2. Inasmuch as the two inputs to COM 2 are identical, an output is routed out of COM 2 to set FF2. FF2 produces the control match (CM) pulse which is fed to AND 7. The output pulse from AND 7 clears FF10 stopping any output from FF10 to AND 8. This action stops AND 8 from passing any of the information coming from the reading head of the "A" register drum. This effectively erases any output from the "A" register while the new information coming from OR 3 is being recorded by the writing head of the "A" register.

The binary number for 127 is now contained in the "A" register drum. Recirculation for the number is from the reading head of the "A" register down through AND 8, AND 11, OR 3, and back to the writing head of the "A" register. Thus, the number 127 is continually taken off and returned to the drum until some new instruction is received.

Carrying Out the Instruction

During phase 2 the computer must route the information in the accumulator (ACC) to memory location 127 and also clear the accumulator. During phase 1 the number placed on the "A" register was decoded to select the channel and sector. Binary 127 is assigned channel 7 sector 15.

The number leaving the reading head of the accumulator is routed through AND 35 since word time and clock pulse are present. It cannot go through AND 37 since an add or subtract pulse is not present from OR 4. Nor, can it go through AND 40 since a copy out and stop instruction is not present at AND 40. Also, it cannot go through AND 38 since no multiply or divide pulse is present at OR 6. Routed to the input of AND 41 the number pulse finds that an instruction of transfer and clear has been routed through OR 7, hence AND 41 passes the number.

The output from AND 41 passes through AMPLIFIER 3 and AND 42 (an address match pulse is present from FF3) to the input of AND 50. The channel decoder is producing an output pulse on channel 7 which is also an input to AND 50. AND 50 passes the number which is routed to the writing head of the channel 7 memory drum and onto the 15th sector.

Add, Subtract, Multiply, or Divide

These instructions are all very similar since they all are arithmetic instructions. To accomplish one of these instructions, it is necessary to route information from the accumulator into the arithmetic unit as well as information from a memory location into the arithmetic unit.

The information from the accumulator passes through AND 35. It will then pass through AND 37, if addition or subtraction is to be performed, and to the ADDER/SUBTRACTOR. If multiplication or division is to be performed, information from the accumulator will pass through AND 38, and to the DIVIDER/MULTIPLIER.

The information from the memory channels passes through any one of eight AND circuits (AND 23 through AND 30), depending on which channel has been decoded in the control section. The outputs of the eight AND circuits are connected in common to the input of AMPLIFIER 2 and then to AND 31. From AND 31 the pulses pass into the ADDER/SUBTRACTOR (through AND 32 or 33) or MULTIPLIER/DIVIDER (through AND 34 or 39) depending on which mathematical function is to be performed.

The answer from the ADDER/SUBTRACTOR or MULTIPLIER/DIVIDER is routed through AND 51 and OR 5, and to the writing head of the accumulator drum.

Copy In or Copy Out Stop

These instructions are utilized to deliver information to and receive information from the computer. Information from the input unit is channeled into the computer circuit as an input to AND 36. The input information passes through AND 36 only when the instruction is copy in (CI) and the word time is present.

When the instruction is to copy out and stop (COS) the information leaves the reading head of the accumulator and passes through AND 35 to the input of AND 40. When the word time and copy out and stop pulses are present at the input to AND 40, the circuit passes the information from the accumulator to the output unit.

All of the instructions are performed only after they have been decoded in the control section.

MAINTENANCE

By running a prepared program such as shown in table 12-1, the TD can determine the computer's accuracy. Understanding how the program is processed through the computer and knowing which circuits are operating according to the logic sequence will make the analyzing of a malfunction relatively simple.

The following examples present the sequence of diagnosing malfunctions which may occur during the test run of the computer. The examples use the program contained in table 12-1 and the computer schematic of figure 12-6.

1. WILL NOT CARRY OUT AN INSTRUCTION: The only circuit which could malfunction to give this symptom is the ring counter No. 1. The computer must be in phase 2 operation when carrying out an instruction. Ring counter No. 1 is the unit which switches the computer into phase 2 operation. AND 1 must be working or the ring counter would not have received a pulse for phase 1 operation.

2. WILL NOT COPY OUT: Copy out is accomplished by taking the desired information from the reading head of the accumulator through AND 35 and AND 40 to the copy out unit. Copy out and stop and word time pulses must appear at the input of AND 40 for the circuit to pass the information. If the copy out and stop pulse is present, it is evident that the INSTRUCTION DECODER is functioning. If the word time pulse is present, FF5 is working. The trouble must therefore exist in the AND 40 circuitry or the reading head on the accumulator.

3. NO ARITHMETIC OPERATIONS: Upon examination of figure 12-6 it can be seen that the arithmetic units (add, subtract, divide, and multiply) are controlled by AND 32, 33, 34, and 39. These AND circuits receive a common command pulse from AND 31. If all the AND circuits are affected, it is evident that AND 31 is probably the trouble. If checking the input pulses to AND 31 reveals that it is receiving inputs but not producing an output, the trouble must be AND 31.

4. INFORMATION CANNOT BE ROUTED FROM CHANNEL 7: Information from channel 7 must pass through AND 22, 30, and 50. Any of these three AND circuits would affect the passing of information.

5. ONE INSTRUCTION ONLY CAN BE PERFORMED: The instruction that can be performed is not important. The fact that only one instruction can be executed indicates that trouble exists in the assigning of the various instructions. The INSTRUCTION DECODER must therefore be malfunctioning. However, the instruction code must pass through AND 14 before entering the INSTRUCTION DECODER. It is evident that one instruction code does pass through AND 14 and indicates that it must be normal.

The above examples illustrate how an understanding of the computer's sequence of operation, as related to the block diagram of the computer, will assist the TD in quickly locating a malfunctioning unit.

AN/UYK-1 COMPUTER

The AN/UYK-1 computer is a high speed, multiple purpose, digital computer. It communicates directly with a main controller and various combinations of peripheral input/output units by means of cables. The computer is also capable of communicating with the Navy Tactical Data System (NTDS) units.

The computer is organized as a parallel 15-bit-word element machine. By manipulation of the 15-bit-word elements, the computer can operate in a variety of modes using word lengths of 15, 30, or 45 bits. It responds to externally controlled interrupts and, after completing the subroutine specified by the interrupting unit, resumes the computation.

The stored logic principle is used to handle various computations and data transfers. In the store logic principle, the memory of the computer controls the detailed operations normally assigned to specific circuits. Instructions not only specify a command, but the details or logic of that command as well. Such detailed logic commands are referred to as logands. A sequence of logands required to perform a specific operation or conventional subroutine function is referred to as a logram (logic program).

The computer's basic memory contains 8192 15-bit words of magnetic core storage, with a 6-microsecond read/write cycle. Data can be received from the external input units at a rate of 33,333 words per second and transmitted out at a rate of 30,000 per second.

PHYSICAL DESCRIPTION

The AN/UYK-1 computer is housed in a single cabinet (fig. 12-7). The control panel and maintenance panel are mounted at the upper portion of the cabinet for ease of accessability. All circuit components for the computer, such as flip-flops, amplifiers, etc., are accessible from the front. More than one circuit is usually packaged on a printed circuit card. Blowers and power supplies are mounted in the rear of the cabinet.

Test points on the various basic circuit cards are color coded to identify their individual function. Location of the circuit cards mounted in the cabinet is coded by number to facilitate quick location. For example, the control panel at the top of the cabinet is assembly 3A1. The maintenance panel is 3A2. The first card from the left side of the next row is 3A3, the next card is 3A4, and etc.

BLOCK DIAGRAM

A simplified block diagram of the computer is shown in figure 12-8. It consists of six 15-bit flip-flop registers designated L, E, M, P, A, and T. A 15-bit, parallel full-adder and a 15-bit, parallel half-adder are also included. An input/output control unit, a core memory, d-c power supplies, a control panel, a maintenance panel, and the various control circuits for operation complete the major units within the computer.

The exchange (E) register, a 15-bit flip-flop register, is used principally for exchanging information or commands with the core memory, and/or any of the other registers. The E register also serves as an exchange for the input/output control section, and is the only register that can communicate directly with the core memory. When the input/output unit has a 30-bit word length requirement, the E register holds the most significant half of the word and the T register holds the least significant part.

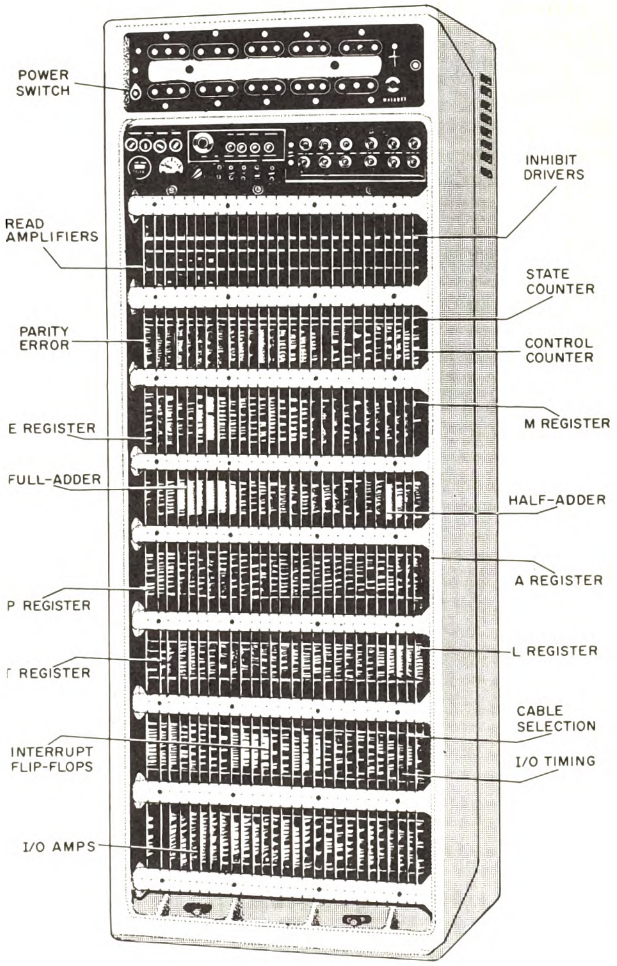


Figure 12-7.—AN/UYK-1 computer.

The input/output (T) register is used principally for transferring data from the computer to the output units. It can be used for transferring outputs while the rest of the computer proceeds independently. The T register can also be used as an auxiliary storage register and may accept data from either the E or the A register.

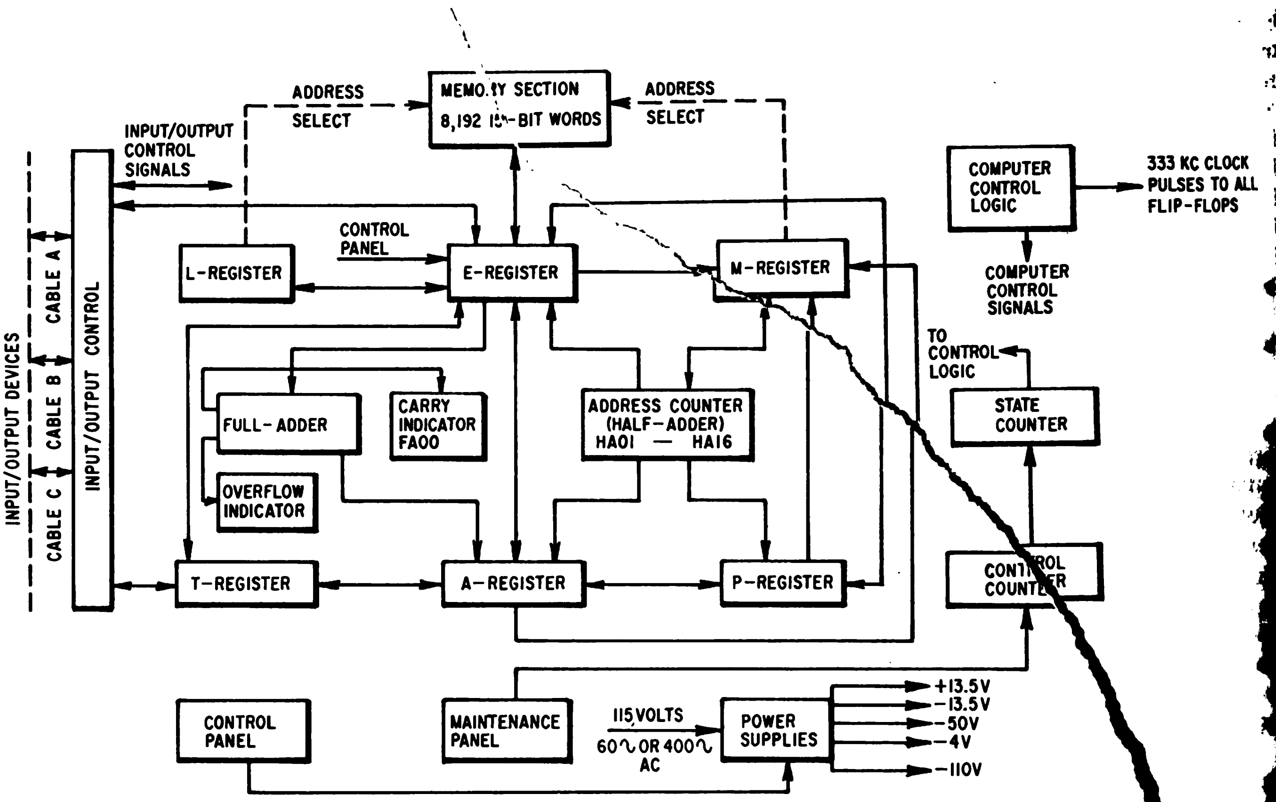


Figure 12-8.—Block diagram of the AN/UYK-1.

The memory address (M) register is used principally for addressing any of the 8,192 locations in the core memory. It operates in conjunction with the half-adder to contain the address of the next logand to be executed.

The arithmetic (A) register is used to hold the results of the arithmetic operations and some logic operations. For example, it holds the most significant part of the product in the multiplication operation and the remainder of a division operation. It receives its principal inputs from the full-adder. However, it may also receive inputs from other registers.

The program address (P) register is used for temporary storage of a program or logand address. It holds the memory address of the next logand while the M register is being addressed from some other location. It holds the least significant part of the product in multiplication and the quotient in division.

The full-adder is a 15-bit parallel adder which is used to form sums and compare 15-bit operands. Each adder position produces a sum digit and a carry digit from the corresponding digits of the A and E registers and from the preceding carry digit. The carry input to the number 1 adder is obtained from the carry indicator flip-flop.

The carry indicator holds the input carry digit during addition, and stores the output carry digit resulting from the addition function.

The half-adder (address counter) is used to increment memory addresses or other addresses by unity. In normal operation, the half-adder accepts the input of the M register, adds on to it and transfers the sum back to M, whic is the next memory address desired. Each adder position has two inputs and two outputs.

The count control flip-flop circuit furnishes the carry input to the half-adder. When this flip-flop is set, the output of the half-adder is one plus the number in the M register.

The overflow indicator is used to indicate the overflow which may occur during a division or addition, or in a data processing logand. The state counter circuitry is a three flip-flop counter which reads out of its circuit a 3-bit instruction defining seven control states of the computer. These seven control states are as follows:

1. Read logand (RL).
2. Write logand (WL).
3. Read indirect address (RI).
4. Write indirect address (WI).
5. Read operand or execute primary command (RP).
6. Write operand or execute secondary command (WP).
7. Hold for input or output (HC).

The control counter operates in conjunction with the maintenance panel to control the state counter. Its operation is independent of the specific logand being performed. Each time a button on the maintenance panel is depressed, the control counter goes through a sequence of states that control the way in which a particular logand or operand is to be terminated. This instruction can call for the computer to stop after a certain sequence or start after clearing a certain sequence. This allows manual operation and control of the programing.

The memory is an 8,192-word random access magnetic core memory. The core array consists of 32 core planes; each plane containing 4,096 cores arranged in 64 columns and 64 rows. The cores in one plane represent one specific bit of a word. Selection of a desired address in memory requires coincident selection of a particular row and column. Associated with each set of two core planes is a read amplifier, which is used for reading out information from he memory. Also associated with each set of core planes in an inhibit driver, which is used for writing in the core during the rewrite cycle of the memory.

COMPUTER OPERATIONS

The computer is normally operated with he main controller and associated peripheral equipment; therefore, the computer operations performed are determined solely by the program and the connected equipment. The computer contains circuitry that allows time for warmup and the only control that requires manipulation s the power ON switch. When all circuitry is n proper operating condition, the computer begins to perform logands. The only procedure ecessary besides programing the computer is oading a blank memory, and some preoperational testing on power supplies.

Preoperational Procedures

The following steps are to be performed at initial turn-on:

1. Turn computer power switch ON. (Fig. 12-7.) The light above the switch should light.
2. Time the warmup interval. Allow 45 minutes for the core to warmup.
3. Check all power supply outputs by setting the selector switch on the maintenance panel for reading the various voltages. If all supply outputs read low or high, adjust the output of the main power source accordingly. If only one power supply is low, check that supply. (This step may be performed during the warmup period.)
4. When the computer has completed warmup, perform the memory loading procedure described below. The computer is now under program control.

Memory Loading Procedure

The following procedure is used in loading the computer:

1. Turn the computer power switch ON and allow normal warmup time.
2. During warmup time, load the input program by inserting the paper tape from the reader.
3. Turn the RUN/STOP switch (on the maintenance panel) to STOP.
4. Set the LOAD switch to the UP position, then release.
5. Turn the RUN/STOP switch to RUN.
6. Allow the tape to run through. Memory is now loaded and if programed to do so the computer will begin running. The computer will not accept the program tape unless sufficient warmup time is allowed.

MAINTENANCE TESTING

The computer diagnostic (testing) program thoroughly exercises and tests the computer's hardware and circuitry to detect malfunctions. Four different tests examine all of the computer elements to be sure the computer will operate as programed.

A control routine allows the computer operator to select any test or combinations of test that he desires. The operator can also select the method by which the diagnostic information is made available to him. The results of the tests may be observed from a typewriter or register neons located on the main control panel. Because the tests are flexible, the operator can select certain parts of a test to be run, or he can rerun parts of tests in which errors have appeared.

After a test has been conducted the typewriter prints out the test completion and records any errors. If an error is found, the typewriter prints out the address of the failing step and circuit. The operator can repeat that portion of the program containing the failing step to doublecheck for a malfunction.

Maintenance Control Panel

The maintenance control panel (fig. 12-9) provides manual control of certain internal functions of the computer. These functions include register transfers, reading or writing with memory, and manual stepping through the logands (logic commands). In addition, the panel contains power supply controls for monitoring each supply.

Mounted on the maintenance control panel are the fuses for the four power supplies. A selector switch allows one meter to monitor each supply. The tolerance of each supply can be evaluated by four marginal check switches. The four marginal switches allow the raising or lowering of the output voltage of the individual power supplies. Four voltage jacks contain the individual output voltage of each power supply.

The running time meter indicates the total time that power has been applied to the computer.

The STOP/RUN switch (when in the RUN position) allows the computer to operate under program control. When the switch is placed in the STOP position the computer can be controlled manually with other switches on the panel.

The manual control switches allow manual operation. The six top row controls (marked E⟷L through E⟷T) provide the manual means by which information can be transferred from one logic register to another. The DISPLAY control clears the E register and enters the contents of the memory location specified by the M register into the E register. The STORE control clears the memory location specified by the M register and writes the contents of the E register into this location. The CLOCK control advances the computer one state at a time and then stops. The LOGAND control allows the computer to complete the current logand (logic command) and then stops.

The program stepping controls also include the FLAG control. This control allows the computer to run until a one pulse is sensed in a logic command circuit at which time the computer stops. The M=SW control allows the computer to run until the contents of the M register equals the settings of the load switches at the main control, at which time the computer stops.

Corrective Maintenance

Maintaining the computer consists of running the test programs described above in order to locate the malfunctioning circuitry. Replacing the failing circuit board requires the extraction of the board and inserting a replacement board. After replacement of the board the test program should be run again to determine the success of the replacement.

If repair of the printed circuit board is required, proper repair techniques must be carefully applied.

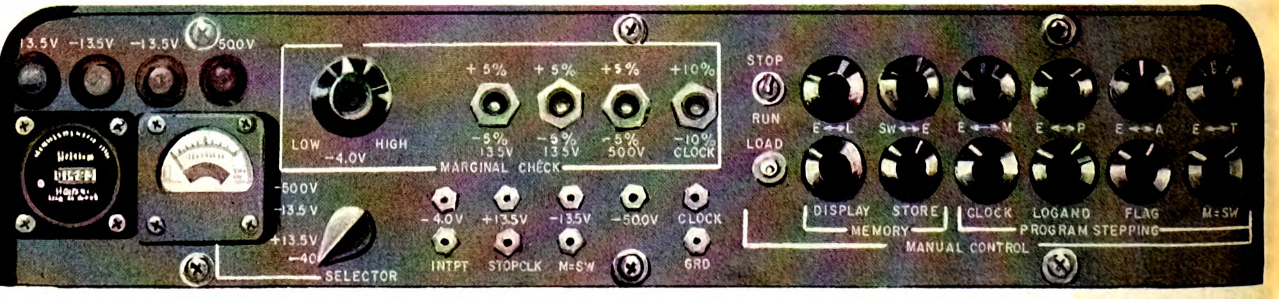


Figure 12-9.—Maintenance control panel.

MAINTENANCE

The upkeep and repair of digital computers present the same general problems that are inherent in all other types of electronic equipment.

The major differences between digital equipment and other electronic equipment are primarily matters of size and complexity. A typical system of equipment containing vacuum tubes might contain 450 components. By comparison, a small digital computer has a complement of 800 to 1,600 units; a medium installation could have 15,000 units; and a large system may have as many as 60,000 components.

In any discussion of reliability, it is a fairly valid procedure to use the number of vacuum tubes as a measure of equipment complexity. Vacuum tubes probably possess the highest failure rate of all electronic components. Therefore, digital computers because of their size, complexity, and the large number of vacuum tubes or transistors they contain, require more maintenance than most other electronic equipment.

PREVENTIVE

There are basically two aspects of preventive maintenance--namely general upkeep and testing.

The first important aspect of general upkeep is regularity. A schedule should be established that includes a complete checkout of the installation within a given time period. Unless this is accomplished, only the easy or interesting work will probably be performed, while the dull or unpleasant work may be neglected. A well-timed maintenance schedule and checklist are generally available in the manufacturer's manuals.

External

External upkeep is concerned with the area in which the computer is installed. As far as possible this area should be conditioned for the installation. This should include equipment for producing temperature control, humidity control, air filtering, and control of other conditions required for proper operation. These specified conditions should be maintained as constant as possible, from the time of installation throughout the life of the equipment.

The area in which the computer has been installed should be uncluttered and clean. The equipment area should be used only by the personnel actually concerned with the computer. The exterior of the computer should be kept clean and free of dust. All bolts, retaining screws, and other items of hardware should be returned to their original places after interior repair or maintenance work has been completed. Drip proof equipment should be kept sealed and watertight equipment should be kept water tight. Shockmounts are used to reduce vibration and must be kept free from paint and dirt.

Internal

The first and foremost preventive maintenance requirement is cleanliness. The computer cabinets should be thoroughly cleaned at scheduled intervals. A vacuum cleaner (handled with caution), a soft bristled brush, and a good commercial cleaning solvent will aid in this job. While the process of blowing out a computer with clean dry air does remove a great deal of dirt, it often packs more dirt into sensitive areas that may be difficult to reach.

Air filters are designed to keep dirt out of the equipment. However when dirty, they tend to reduce the circulation of air. A commerical filter can normally be cleaned by removing it, washing it in detergent and warm water, drying it thoroughly, and then coating it with a prescribed type of light oil.

There have been many occasions when a strange, intermittent trouble symptom has finally been localized as being caused by a loose terminal-board connection or a dirty component socket. All terminal-board screws should be tightened, and tube sockets, plugboards, jacks, switch and relay contacts, etc. should be burnished or periodically cleaned with a good specified solvent.

Many computers are built to provide rapid and easy access to the individual components. Sections of the cabinet swing out to facilitate inspection and maintenance. They should be checked for abnormal frictional restrictions that could indicate contact with cables and other components. A cable run may become unclipped and rub against a movable section or drawer. Cables should be kept in place, and drawers should be checked to insure that no rubbing or forcing is taking place.

Lubrication

Correct lubrication procedures are usually specified by the manufacturer and should be performed in accordance with these instructions. Caution should be exercised to avoid both carelessness and overlubrication.

Spilled lubricant and lubricant that has been thrown by moving mechanical parts, form dangerous and troublesome dirt and dust collectors. Unfortunately, some lubricants also produce a deteriorating effect upon insulating materials and can be responsible for the formation of high resistance connections on contact surfaces. Great caution should always be observed when using lubricants.

Tools

Effective maintenance can only be maintained by using the proper tools. Digital computers require special tools as prescribed by the computer manufacturer. An accurate inventory of these tools should be maintained. The Tradevman should develop the habit of using the correct tool for each job. If a tool breaks or mars the part being worked on, the proper tool was not used.

CORRECTIVE

As the complexity of electronic computers increases, it is reasonable to expect that the problem of maintenance will also increase. A 500-circuit computer may be 5 times as difficult to maintain as one containing 100 circuits. Unfortunately the permissible "downtime" of the latest and more complex equipments is growing less.

Digital computer performance is affected by many factors. The operation of each circuit, section, and input-output unit is so interrelated that overall system tests are the only way to determine if the computer is operating properly. Unlike a radar system which can operate at reduced efficiency, a digital computer is a yes/no equipment. The computer is either operating properly or it is malfunctioning. Optimum performance of a digital computer requires a corrective maintenance program to detect and repair troubles before the computer actually goes "down."

Troubleshooting

Troubleshooting using the "system-test" program and the "diagnostic" (or trouble localization) program comprises two excellent computer maintenance methods. In most cases these test programs are prepared by the computer manufacturer. If this is not the case, then the maintenance supervisor must initiate a prepared program.

The system-test program consists of a sequence of operations that will indicate whether or not each section of the system is operating correctly. It will generally localize a particular malfunction to a large subsection, such as the control, memory, arithmetic, or input-output units. The program is an ordered sequence of instructions to the computer, which involves the normal operations and components that the computer would use to solve any other problem. The program is inserted into the machine in exactly the same manner as any other program, and operates by checking the characteristics of the computer as a system. The prepared program is somewhat more stringent than most problems, since they are designed to give the computer a thorough "workout."

The basic principle employed in all test programs is that an operation is performed, and the result is compared with the precalculated correct answer. The entire program consists of automatic calculation, comparison, and then further calculation and comparison. The computer is programed to stop when the result of a calculation does not agree with the correct result. A program step counter is usually used to indicate the step in the program at which the computer has stopped. The maintenance man, knowing which circuits are used to perform each step, is thus informed of the region in which the circuits are not functioning properly.

The computing comparison process is accomplished by inserting a correct answer into a register, and then programing the problem that will produce the correct answer. By subtracting one of the two answer registers from the other, the computer senses the results (answer should be 0). The computer must also be programed to proceed to the next step if the results are zero, and to stop if they are not.

The diagnostic program is a specially prepared program which is either built in as an integral part of the computer or externally applied. This procedure is generally performed during scheduled "downtime" of the computer. The computer evaluates itself and diagnoses any malfunction which occurs.

The program exercises various functions in the computer, checking these functions for proper operation. If the result of the program is other than expected, the computer automatically institutes an error locating program. This exercises additional investigating functions, with the computer rendering decisions about the probable location of the error. Upon detecting a malfunctioning circuit the computer either prints out the answer on a typewriter or punched tape, or energizes coded neon lamps on the maintenance panel.

The additional exercises referred to above are called marginal checking programs. A circuit is expected to operate between certain upper and lower limits of tolerance. The tolerance of each component is weighed during circuit design to establish the circuit tolerance. Ideally, the circuit operates in the middle of its design tolerance range. In this way, variations, either up or down, may be tolerated without circuit failure.

The marginal checking program examines circuit operation over the entire tolerance range by running the supply voltages up and down, and by changing the amplitude and frequency of the signal inputs to, and slightly beyond, the full design limits. If the circuit cannot "take it," a failure will result. In this way, forthcoming failures can be predicted during scheduled downtime, thus improving reliability.

Transistorized Circuits

The development of transistors has advanced electronics by providing a more reliable replacement for the vacuum tube. The development of equipment containing more circuits in a smaller package has been aided by the smaller size of the transistor. The principles of the transistor are contained in Basic Electronics, NavPers 10087-A.

Digital computers contain hundreds of transistors mounted on printed circuit boards. One board may contain several transistors, the associated components, and wiring.

A great deal has been published about exercising care in soldering transistors, expecially to provide a heat sink to avoid damage to the transistor. Other precautions should be followed including procedures for inserting and removing transistors from their sockets. Insert and remove transistors from their sockets only when the current is turned OFF. To do otherwise may damage it. Removing the load from a transistor circuit may affect the current drawn through the transistor, with the possibility of an overload causing damage.

Miniaturized Components

The development of complex circuits has required that more circuits be mounted in as small a unit as possible and has fostered a technology known as miniaturization. Miniaturization has produced smaller components such as electronic components, motors, relays, transformers, etc.

Miniaturization in the field of electronics has developed entire circuits, including transistors, resistors, capacitors, and all connecting linkages built into one rock-like solid state unit. These units are sometimes called microcircuits. Some of these solid state circuits are so small that a magnifying glass is required for visual inspection.

Modules and Potted Components

The packaging of components into one small unit is called a module. Modules are easily removed from specially designed racks which provide mounting slots to hold the modules and receptacles to electrically connect the circuitry into the equipment. By identifying a malfunctioning module, the Tradevman can quickly extract the module from its rack and insert a good module, thereby decreasing maintenance time.

Potting of circuit boards is used because the operating time between repairs can be considerably increased by its use. The sealing of components prevents their exposure to moisture. The potting is first done by the manufacturer at the time of installation of the components. Portions of the components are potted together as a unit and are mounted on the circuit board (fig. 12-10).

Maintenance of potted components begins with the necessity of removing the potting compound. This problem should be minimized by the fact that most potted sections do not require repair. The manufacturer's maintenance manual should provide the decision whether or not to remove the potting. If the removal is necessary, the manual should contain illustrations and instructions of the sections to be repaired. The potting compound on some assemblies is easily removed because the assembly was enclosed in a plastic bag prior to potting. In this manner the assembly is potted but the compound is prevented from flowing around or adhering to the detail parts. Circuit boards which are potted in this manner can be cleared by cutting a parting line around the edge of the lamination and removing the two halves.

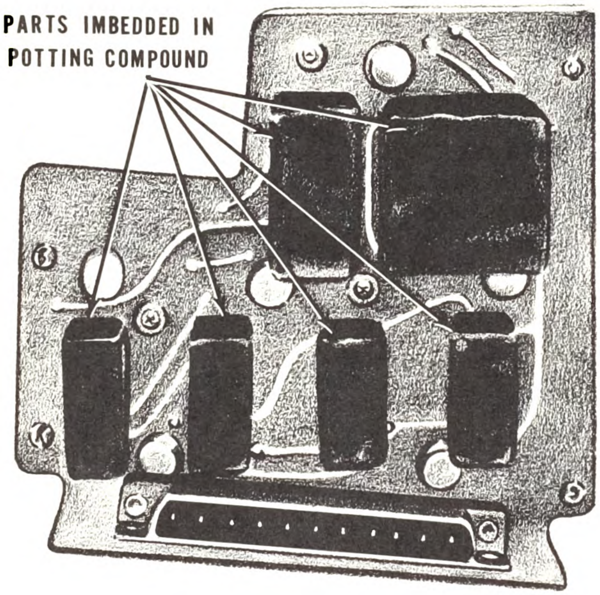


Figure 12-10.—Potting.

The repair of this type of assembly is the same as that required of all circuit board assemblies, except for the additional problems created by the potting materials. After repair has been performed, the potting material must be restored in accordance with the instructions contained in the manufacturer's maintenance manual.

Printed Circuit Boards

Printed circuit boards have become common items in electronic equipment. Their development is a result of the trend toward miniaturization. In the process of eliminating maintenance problems encountered with the standard method of mounting components, the handling of printed circuit boards have presented new ones.

Printed circuit boards are made up of an insulating base material (lamination), conductors, feed through couplings, and hardware and parts. In addition to these items, solder, flux, and protective coating play a very important part. The base material is the structural member of a circuit board assembly. It is used to support and position the conductors (copper foil), hardware, and parts. The thickness of the board averages about one-sixteenth inch thick and is fragile. Care must be exercised in handling to avoid twisting the board as the copper foil conductors crack very easily.

Protective coatings are common items on printed circuit boards. They are necessary to protect the components, conductors, and laminations from environmental defects. However the coatings present maintenance problems. The specific coating materials vary from shellacs and varnishes to potting compounds. These materials are applied by brushing, spraying, or dipping. The thin coating is applied over the entire surface of the assembly. Prior to repair of circuit boards, the manufacturer's maintenance manual should be reviewed concerning the materials and procedures to be used for removal of and replacement of the protective material.

One of the first steps required in repairing circuit boards is visual inspection. A thorough visual inspection may reveal defects caused by physical damage to the lamination, conductors, parts, leads, and protective coating. A magnifying glass is required for close examination. Some defects are so minute that, without magnification, they are very difficult to find.

Inspection of the lamination (baseboard material) may disclose dust, dirt, grease, wax, solder drippings, paint, pencil marks, filings, adhesives, or any other type of foreign substance. The lamination may show evidence of a scratch caused by rough handling or a sharp tool. This may indicate a broken conductor. A burned spot on the lamination indicates an overheated component which may be the cause of a malfunction. Moisture penetrating the protective coating may be the cause of a component failing.

Visual inspection may discover the basis of trouble to be peeling of the copper foil conductor. The solder joints are a source of possible trouble. Corrosion on the soldered joints indicates that a flux other than rosin has been used during soldering. Excessive amounts of solder is a good place for bridging or shorting circuits where no connection should exist.

Sharp bends in wiring and component leads are sources of possible trouble. The sharp bend may cause a mechanical strain on the contact at the printed circuit and become loose due to handling and vibrations. The mounting of components (fig. 12-11) is very important to successful maintenance. If the component is not properly mounted possible future malfunctions are likely to occur. Some of the results are illustrated in figure 12-11.

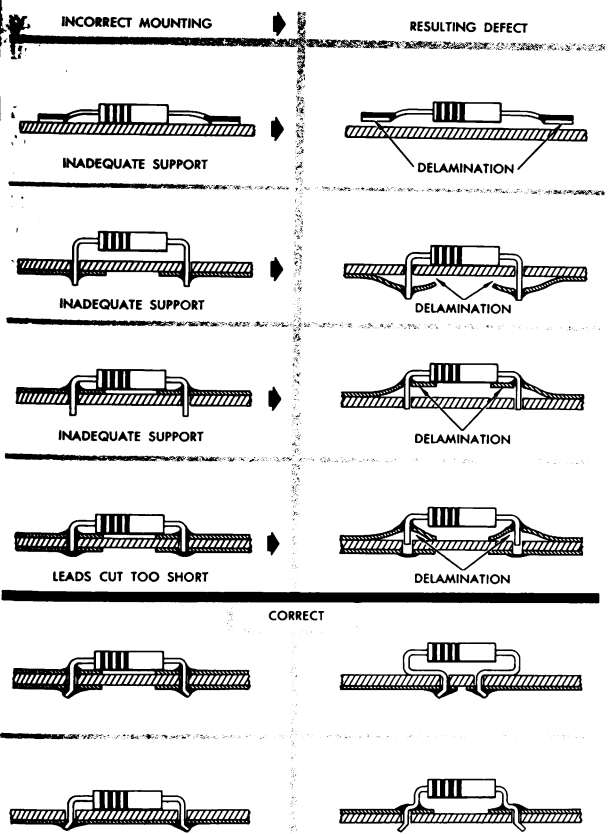


Figure 12-11.—Component mounting methods.

Connectors, plugs, jacks, and sockets are ources of possible trouble. Close inspection hould be conducted to insure cleanliness and irmness of contact. Connector pins should be nspected for possible wear, pitting, corrosion, urns, or misalinement. Sliding contact connecors should be cleaned periodically to insure ood contact.

Variable or adjustable components such as otentiometers, variable capacitors, and variale inductors are susceptible to failing when ounted on circuit boards. They should be nspected to insure their firm mounting and ircuit contact to the printed board.

The printed circuit board should be clean nd dry. Any foreign substance may act as a oisture trap and may short out components. or this reason printed circuit boards should e handled with gloves. Removal of dust and ther foreign particles can be accomplished by sing a soft nonmetallic brush and a low pressure ir jet. Use air from a source that supplies dry iltered air. Embedded particles can be removed with a sharp probe or knife point. Further cleaning can be accomplished by using a mild cleaning solvent as prescribed in the manufacturer's maintenance manual.

If a small crack is detected in the lamination, its progress can be stopped by drilling a 1/8-inch hole at the point where the crack appears to stop. This hole impedes further progress of the crack. With a sharp knife trim off the rough edges along the crack. Trim the crack to a minimum width of one-sixteenth inch. Apply protective coating inside the stop-drill hole and to the edges of the crack. This fills the crack and may save the board.

A burned spot in the laminate baseboard may be replaced. A rectangle is formed around the burned area with a drill. Upon removing the rectangle of burned board, smooth and straighten the edges of the created hole. Apply the appropriate protective coating material which seals the laminate board.

If a crack in the conductor strip is detected, it can be repaired by first carefully removing the protective coating on the board. This is accomplished by using a chisel tipped (low wattage) soldering iron (fig. 12-12). Keep the tip moving to prevent further damage to the conductor and lamination. Apply a small amount of flux to the surface of the conductor where the solder is to be applied. Then apply a solder patch to the damaged area. Remove excess rosin from the soldered area with a cotton swab dampened with isopropyl alcohol (MIL-I-10428). Next wipe the entire area with a lint-free cloth dampened with methyl-ethyl-ketone (TT-M-261B). The last operation is to apply the protective coating to the repaired area.

In cases where the crack in the conductor is too large to repair by this method, a satisfactory repair may be made by installing a segment of wire to connect the two terminal ends of the printed conductor. As in the case of all repairs, the board should be coated before using.

Tools and Facilities

The maintenance of printed circuit board assemblies requires a suitable work area and adequate tools, equipment, and materials. The work area must be large enough to accommodate workbenches, storage cabinets, test equipment, and materials, and still leave adequate space to provide uncrowded work areas. The area should be further assigned into a specific area for

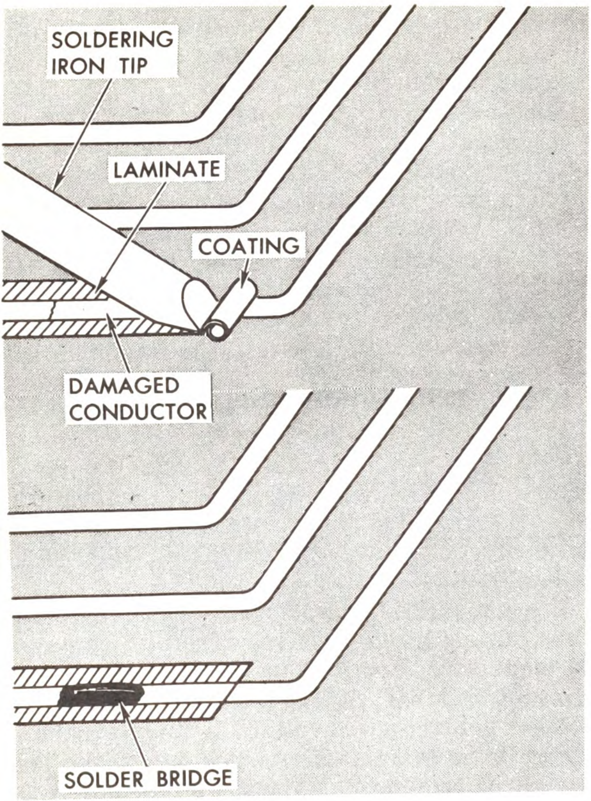


Figure 12-12.—Removing protective coating.

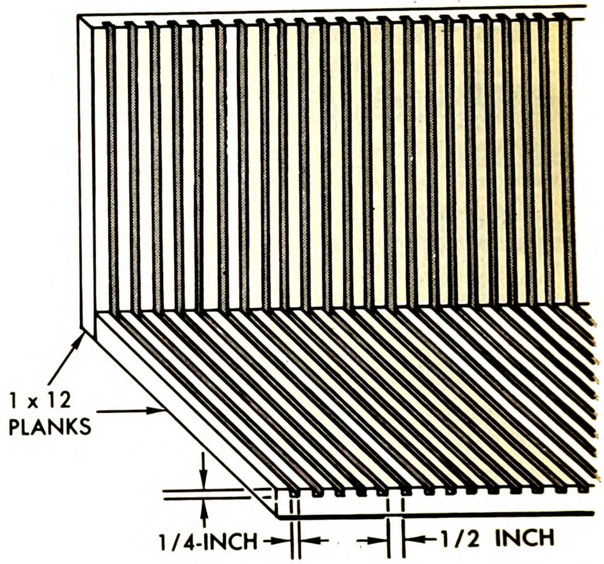


Figure 12-13.—Circuit board storage shelf.

roubleshooting, repair and replacement, protective coating application, and storage. The rea should be enclosed and air conditioned to revent the contamination of the circuit board ssemblies by dirt and moisture.

Cleanliness and humidity control are two ery important factors in circuit board maintenance. Lighting is another important requirement. Due to the miniaturization and close spacing of circuits and components, maintenance requires good overhead lighting with provisions or adjustable close lighting on the workbenches.

The storage area is used for the storage of circuit board assemblies, tools, equipment not n use, materials for the protective coating process, records, related maintenance publications, and materials and parts required for the repair operation. Storage for the circuit boards must be capable of holding the circuit boards in vertical position. The parts are exposed and easily damaged; therefore, they should be stored separately and in a vertical position in a rack similar to the one shown in figure 12-13. The storage of some protective materials may require refrigeration.

The troubleshooting and repair area should consist of a bench area, adjustable light fixture with magnifying glass, a pegboard (or similar fixture) for storing tools in an easily accessible manner. A complete assortment of handtools, soldering irons (with desoldering accessories), soldering aids, and a variety of heat sink tools are required for printed board maintenance. A suitable holding fixture should be available for holding the circuit board during repair. If a commercial unit is not available one may be fabricated as shown in figure 12-14.

The area set aside for the application of the protective coating should include a bench area with an adjustable holding fixture with suitable lighting. It should also include an exhaust fan or hood over the bench area and a low pressure source (15 psi) of filtered air. An assortment of small items such as mixing cans, stirring paddles, brushes, dipping vats, lint-free cloth, spray guns, etc., will be needed. The extent of the provisions is determined by the type of protective coating prescribed by the manufacturer. A washbasin should be provided for the purpose of washing off any of the materials used in the coating process which come into contact with the skin. Some of these materials are possible irritants to the health of the individual.

Safety Precautions

The only hazards involved in the maintenance of printed circuit boards are those that would be encountered in any electronic maintenance activity. However, the solvents and some of the materials used in the protective coating process require the following precautions:

1. Flammable liquids must be stored in approved containers and enclosures.
2. Some liquids are possible irritants and somewhat volatile. Do not allow liquids to come into contact with the skin. If it happens accidentally, wash the area immediately with soap and water. Use an apron and gloves.
3. Use solvents and coating materials under a hood or exhaust fan to avoid inhalation of fumes.

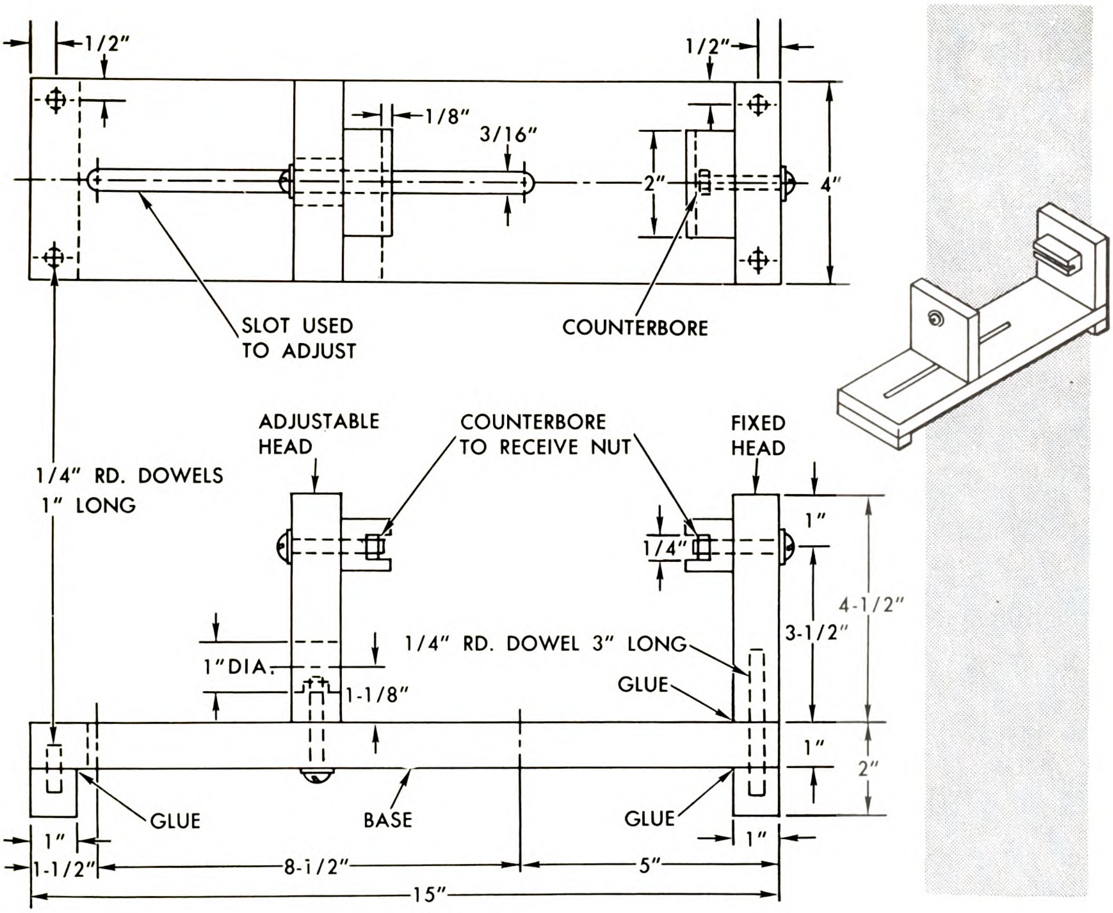


Figure 12-14.—Circuit board holder.

CHAPTER 13

TACTICAL TRAINERS

The rapidity with which the military research and development program is moving demands new and more effective methods of raining men in highly complex skills. The variety and the complexity of skills to be earned by military personnel within the pressing ime limits present a formidable training probem. However, training time can be substantially reduced by the use of adequately designed and properly utilized training devices. One method of training dividuals or groups is by the use of synthetic trainers.

The training of individuals or groups while utilizing methods and equipment to create and present actual operational or combat conditions s called synthetic training. Fleet and air maneuvers, battle practice, drills, and exercises may be considered part of a synthetic training program that has been used for years to prepare the Navy for actual operational emergencies and for combat. The equipment used n synthetic training to simulate emergency and combat conditions are referred to as simulators r tactical trainers.

A simulator or tactical trainer may be described as the equipment which accurately computes and simulates the conditions and functions encountered by personnel in performing their tactical mission. A simulator may be a small black box which activates the operational equipment, thus providing an operator with the indications necessary to solve a actical problem. In another instance the simuator may be a full size model of a submarine r aircraft in which the crew may operate equipment identical to that in the operational vehicle. A training device which provides training of a complete crew in a complete system simulator is called a weapon system trainer.

The descriptions of the trainers contained n this chapter are presented to show the application of operational tactics in complete simulated training spaces. A detailed description of the equipments is beyond the scope of this training course but can be found in the individual trainer's utilization and maintenance manuals.

ASW WEAPON SYSTEM TRAINER

An intensified training program for Navy aircraft crews engaged in antisubmarine warfare (ASW) is being carried out at coastal training commands.

The classroom is a flight and tactics simulator of the four-man twin-engine S-2D (S2F-3) aircraft. Technically, the training device is known as the 2F66 Weapon System Trainer. It is said to be "double time" because the training unit has crewmen training in it approximately 16 hours a day. If the actual equipment, including an aircraft and submarine (acting as the target) were to be used for training on a schedule equal to that of the simulator, the difference in cost of training would illustrate the simulator's value. The realism provided by the simulator reproduces all the operational details of the aircraft.

The trainer combines basic aircraft simulation with that of an antisubmarine warfare mission. It makes training possible for a four-man crew to search for, detect, classify, localize, attack, and destroy simulated underwater targets. Thus, the pilot and crew receive considerable experience in a relatively short time and are more capable of taking over an actual aircraft after safely forming their flight habits in the simulator.

The simulator is contained in two mobile commercial van-type semitrailers. One of the trailers contains the 32-circuit computer unit that controls the simulator. The other trailer contains the simulated aircraft and stations for the two-man instructor and operator team that trains the crew. Installing the simulator in vans eliminates the need for a special building and permits the placement of the training device near the flight line.

The training crew, which consists of a pilot, a copilot, and two ASW operators, work as a team in the aircraft and fly the simulator (fig. 13-1). The trainer cockpit is the same as the aircraft's interior. The pilot and copilot, provided with all the instruments and controls they would have at hand during an actual flight, receive simulated responses identical to those received in the actual aircraft.

Since the aircraft must perform its mission on an all-weather basis, it is important to train the pilot and crew in the tactical use of the aircraft under instrument conditions. For this reason, the windshield of the trainer is translucent and all training is conducted under either day or night instrument conditions.

The two ASW operators also fly under accurately reproduced conditions. They look for potential enemies with the help of actual control panels, instruments, and scopes that provide them with simulated responses from radar, electronic countermeasures (ECM), advanced detection systems, and other electronic equipments.

Every instrument functions in true relationship with other instruments in a simulated flight. Airspeed changes as flaps and landing gear are raised during the takeoff. Instruments

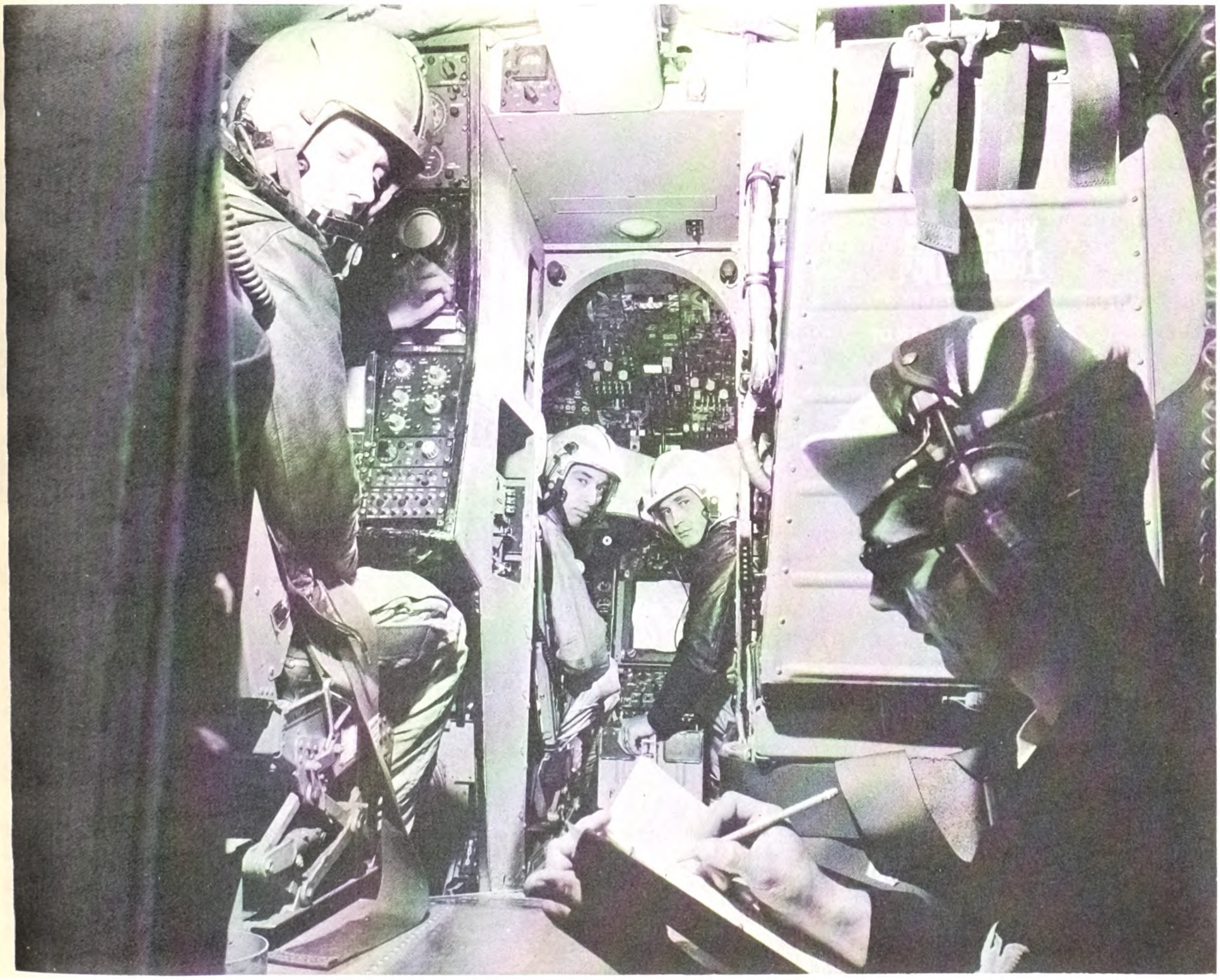


Figure 13-1.—Aircraft simulator, device 2F66.

reflect changing characteristics such as fuel load, altitude, attitude, and speed (power).

In addition to the normal operating conditions, the pilot and his crew can be presented with practically every conceivable emergency by the instructor and operator.

The instructor has in front of him a duplication of all the essential instruments and indicators in the cockpit. In addition, he is provided with numerous lights that indicate incorrect procedures. These lights and the cockpit instruments permit him to monitor both the flight and ASW mission from the instructor's station.

Failure input controls (fig. 13-2) and switches are used by the instructor and operator to introduce partial or complete failure of components. These can be in the form of engine failure, decreasing oil pressure, icing, in-flight fires, and other emergencies.

The instructor can alter physical flight conditions by supplying clouds, thunderstorms, and similar effects. This is accomplished by causing the crew seats to bounce during rough air conditions, vibrations and engine sputter during engine trouble, the screech of tires during touchdown, and variable shadow effect of clouds.

Cold cathode lighting tubes produce simulated lightning flashes. The effect of flight in and out of clouds is produced by rotating disks

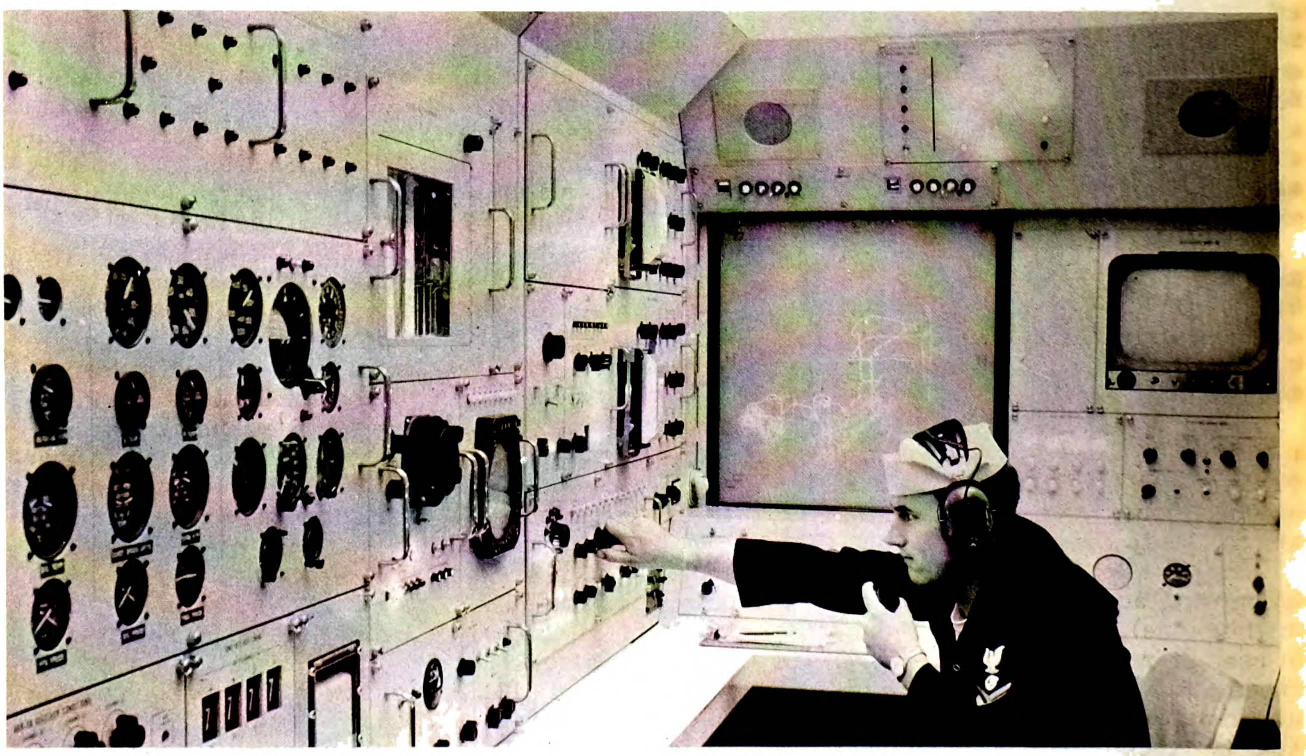


Figure 13-2.—Control station, device 2F66.

with openings that are mounted in front of lighting fixtures to cast light and shadows in the cockpit windows. Two speakers, one behind the pilot and one behind the copilot, provide engine noises, both normal combustion and sputter from a faltering engine.

The instructor is in control during a training session. He establishes problems to be given to the crew, monitors progress of the flight, and observes the crew's reaction to problems. The simulator operator manages controls for the training session.

The instructor can vary problems as crew proficiency increases. He has "freeze" and reset controls that permit him to "freeze" action in the simulator to analyze an incorrect action, and then either reactivate or eliminate the problem. This "stop-go" capability increases the advantages of the trainer.

The plotting board presents to the instructor the path and location of the aircraft and submarine at any moment of a mission. It also records events chronologically for debriefing. The instructor originally positions the aircraft and submarine targets on the plotting board; then controls evasive actions of the submarine as it attempts to escape the searching aircraft. He also can control speed, position, and depth of the submarine as well as the origination of radio or radar transmissions from the submarine and the variations of wind and sea conditions.

The training crew, airborne over the ocean, presumably is on a search plan. The instructor, freed from the responsibility for the safety of a crew under actual flight conditions, is able to devote all his time to observing and training the crew.

As many as three targets may be tracked at one time. The crew is provided with radar (to "see" the target), ECM (to detect electronic transmissions), and other detecting equipment used to locate the target.

Once the general location of a target is determined and identification is made (friendly or otherwise), a system of explosive echo ranging is used for target localization. Small depth charges are dropped to activate the sonobuoys, and the student operator measures the time from blast to receipt of the blast echo from the target through a recorder in the aircraft. Radio receivers permit the pilot and copilot to listen to the transmissions of these sonobuoys.

Throughout the exercise two other means of detection operate to help pinpoint the target. One is magnetic anomaly detection (MAD), a sensitive magnetic airborne detector capable of measuring changes in the earth's magnetic field. The other detector is the "sniffer." This equipment samples air from the local atmosphere to detect the presence of a submarine. The air is pulled into a special chamber and is processed and evaluated by the system.

Once the target is pinpointed, an intervalometer is activated in the aircraft (simulator) which automatically times and drops sonobuoys; thereby assuring accurate spacing between the sonobuoys.

Weapons in the system are advanced homing torpedoes and an atomic depth charge. The training crew hears the detonation of the weapons.

The pilot and copilot have a plotting board in the cockpit of the simulator that gives them a continuous display of their aircraft's position within a designated area. Depending upon the phase of the mission, the board may be controlled to represent 1, 4, or 20 square miles per square inch.

Position of the aircraft on the plotting board is indicated by a moving marker that marks the flightpath and moves from the center of the panel in the direction the aircraft is moving. For tactical use, the range and bearing of the suspected target may be entered into the system. Using this information the marker traces a course to the area, marks it and returns to the aircraft position on the board. This enables the pilot to fly the aircraft to the area and continue with other ASW procedures.

An armament control panel controls the switches for arming and selecting the stores to be dropped and for operating the torpedo bay doors. It is on this panel that the intervalometer and rocket selection units are located. Airspeed, drop interval, and weapons are provided for by controls (also on this panel). These controls also enter the ground speed of the aircraft into the system.

The sonobuoy indicator panel in the cockpit contains 32 indicator lights divided into 2 groups of 16 each; the lights become illuminated as sonobuoys are released. A twin receiver, 16-channel FM set is used to receive signals from sonobuoys that have been dropped and are being used to locate the position of an enemy submarine. Operation of channel selector switches determines which sonobuoys are to be monitored at any particular time.

Many different types of sonobuoys are used in detecting underwater sounds. Each contains a hydrophone and a transmitter for relaying detected sounds to receiving equipment in the aircraft.

HELICOPTER SIMULATOR

The helicopter simulator, device 2F64 (fig. 13-3), is capable of duplicating the full performance range of Sikorsky's all-weather, sonar equipped SH-3A (HSS-2) helicopter. The simulator trains helicopter pilots and sonar operators individually or as a team.

The SH-3A is designed for use as a component of an ASW force. Tasks that it can perform are detection, tracking, and destruction of enemy submarines; ASW convoy escort; sea rescue services; barrier tactics; screening tactics; and visual reconnaissance.

The foregoing tasks involve employment of the helicopter during daylight, night, or instrument flight conditions. A high degree of skill is required of the crews to execute their missions. The device plays an important part in developing and maintaining the proficiency demanded of these helicopter crews.

The instructor student type device is used for transition training of personnel assigned to duty in SH-3A squadrons. The pilot's training consists of familiarization with the flight characteristics and the systems of aircraft under both normal and emergency conditions. A second

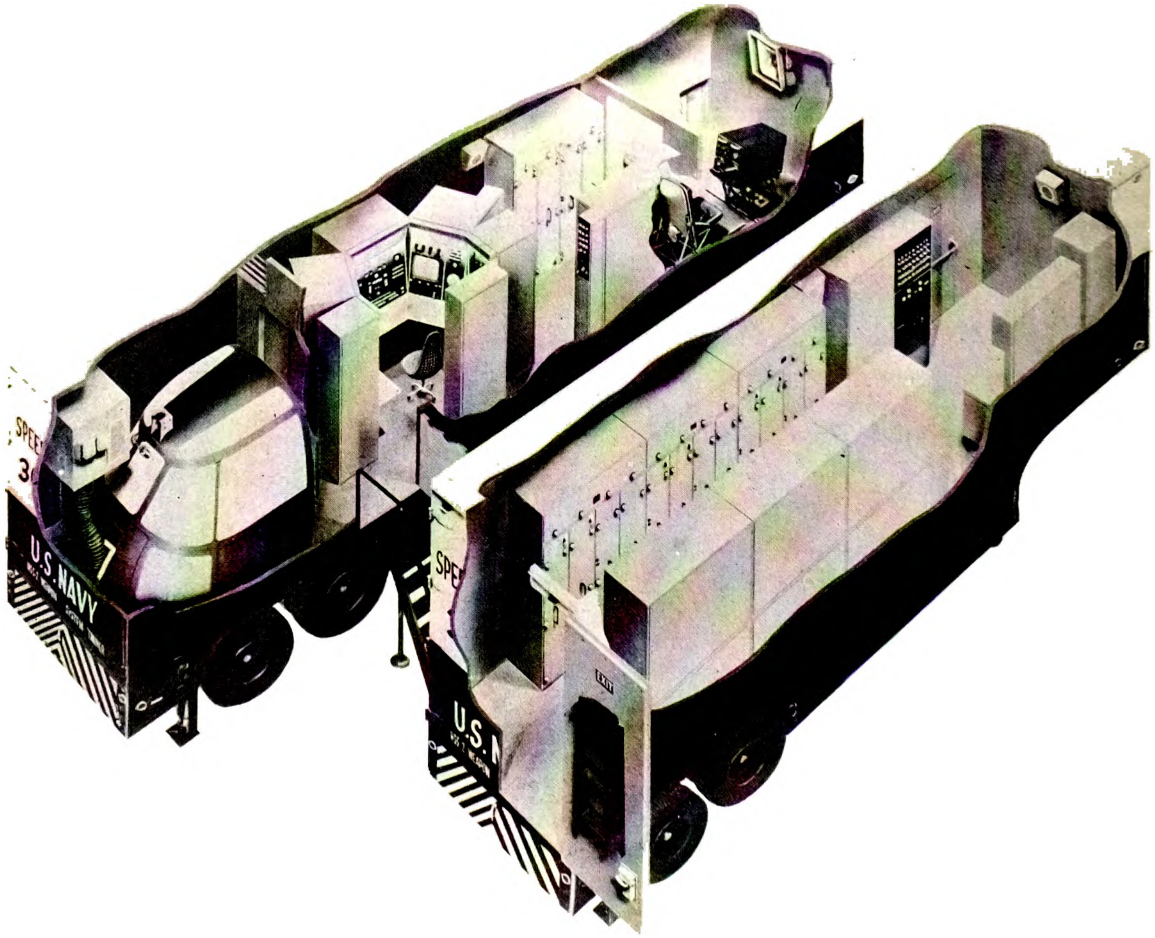


Figure 13-3.—Equipment trailers, device 2F64.

objective is to develop crew proficiency in all phases of the SH-3A mission. This includes familiarization and advanced training for sonarmen assigned as operators for the AN/AQS-10 Sonar Set, an integral part of the SH-3A system. The simulator is also utilized to develop the combined pilot-sonarman skills required of the ASW team. The simulator is used to train all phases of tactical missions, including communications, navigation, ASW search procedures, target detection, target classification and tracking, and the delivery of weapons for destruction of the target.

In order to fulfill these training objectives, the equipment simulates the following five major categories:

1. Aircraft systems.
2. Radio navigation aids facilities.
3. Environmental conditions.
4. Tactics portion (sonar).
5. Operational malfunctions.

The aircraft simulation includes the aerodynamics of flight for the full performance range of the aircraft, as well as the behavior of 20 of the aircraft systems including oil and fuel, hydraulic, blade folding, landing gear, and armament. The flight control equipment in the trainer duplicates that of the actual aircraft. The forces felt on the trainer's control stick and rudder pedals during normal operations are the same as those in the actual aircraft. The automatic stabilization equipment (ASE) of the SH-3A is completely simulated. The pilot's attempts to overcontrol the aircraft (trainer) are also faithfully reproduced.

The trainer simulates the radio aids and navigation equipment that makes all-weather operation of the SH-3A possible. Included are the compass system, radar altimeter, the APN-130 Doppler radar, and other components of the navigation system. Also provided are AN range transmitters, low frequency tower stations, homing beacons, TACAN stations, plus a UHF transmitter, and GCA control.

Simulated are temperature and atmospheric pressure variations, wind force, ambient light and cloud effects, lightning, rough air effects proportional to airspeed, and engine and rotor icing. Sounds of the helicopter's main gearbox, the engines, and the accessory drive system are mixed in ratios to produce the sounds heard by the pilots and the sonar operators at their respective stations. Aircraft vibrations are generated by a cockpit suspension frame driven by a hydraulic ram in accordance with computed inputs. These inputs comprise rotor and power setting effects. Exceeding limitations either in flight or in landing activates "crash" signals. The cause of the crash is indicated on the instructor's monitoring panel.

The tactics portion of the trainer simulates targets, water conditions, and the characteristics of the AN/AQS-10 sonar in its various modes of operation. Facilities are provided for the activation of five targets by the instructor. Their speed, rate of turn, heading, location, and depth can be suitably controlled. Oceanographic conditions such as sea state noise, bottom effects, and detection range are also established from the instructor's station. Variation of these controls influences the sonar displays and aural signals appropriately.

Through the use of fail switches, variable controls, circuit breakers, and monitoring indicators, instructors can introduce malfunctions, failures, or other emergency conditions that could occur in the SH-3A aircraft. Failures and their effects can be introduced in the aircraft systems, communication, navigation, or tactics portion of the trainer.

Details of the helicopter cockpit area (fig. 13-4) insures that maximum identity with the actual aircraft has been retained. The cockpit used in the trainer (fig. 13-3) is that of the SH-3A aircraft, modified only to the extent necessary for its adaptation to synthetic trainer functions. The sonar compartment configuration duplicates that of the aircraft to the extent of an enclosure with approximately the same interior shape, bulkhead covering, lighting, and air-conditioning duct. The sonar indicator control console, center console, and seats duplicate the actual aircraft.

The instructor's station (fig. 13-5) is designed to permit one- or two-man operation. One sonar and one flight instructor can conduct independent sonar and flight problems simultaneously. Coordinated flight sonar problems may also be conducted by either one or two instructors. Single instructor operation at this station is considered feasible because there is no sonar search activity while the pilots are flying the helicopter to a sonar search area. Conversely, when the dipping and search operations commence, activity in the cockpit is reduced.

The trainer is housed in two mobile, air-conditioned trailers (fig. 13-3) designated as the personnel trailer and the equipment trailer. The trainees' compartments and the instructor's

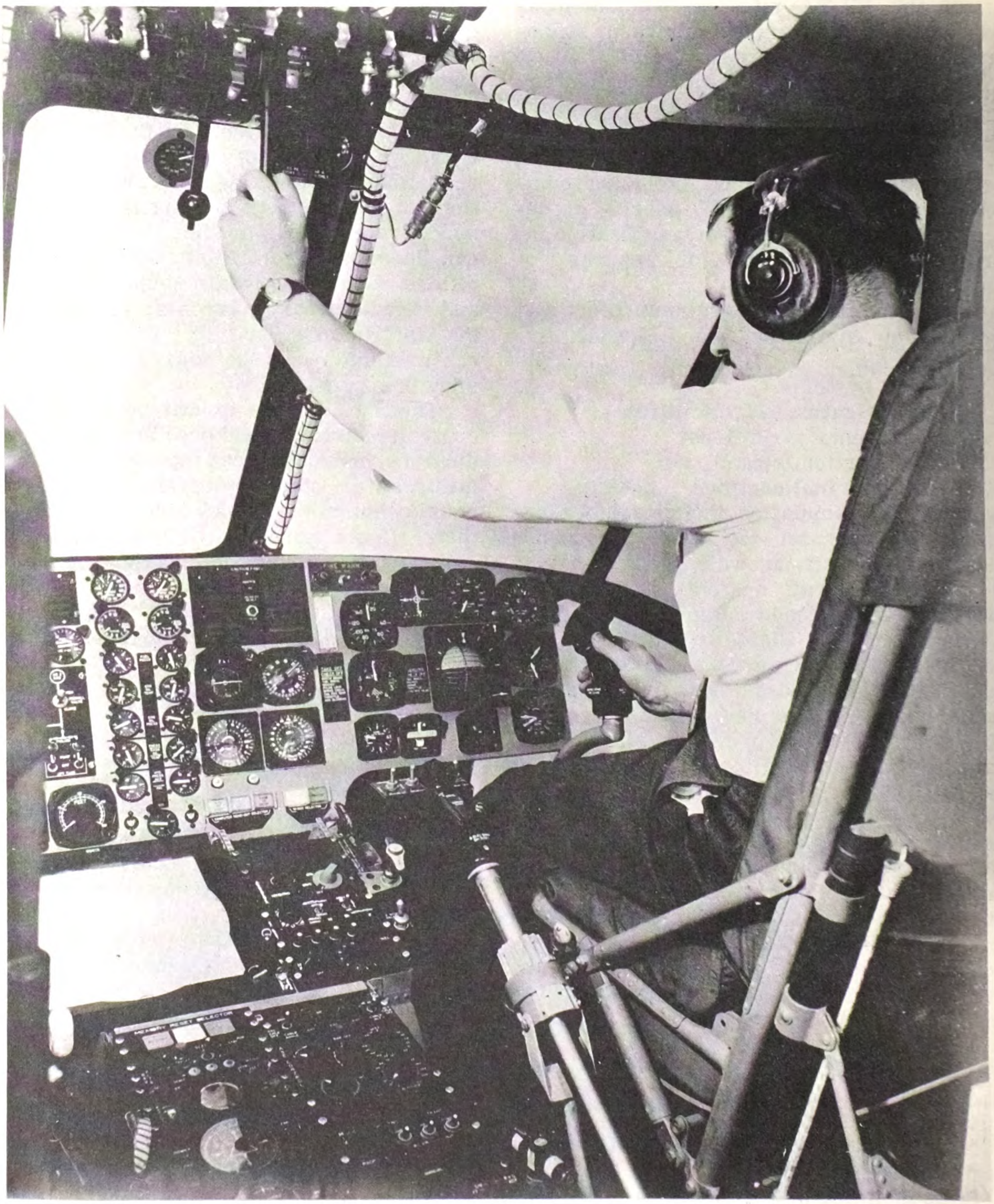


Figure 13-4.—Cockpit, device 2F64.

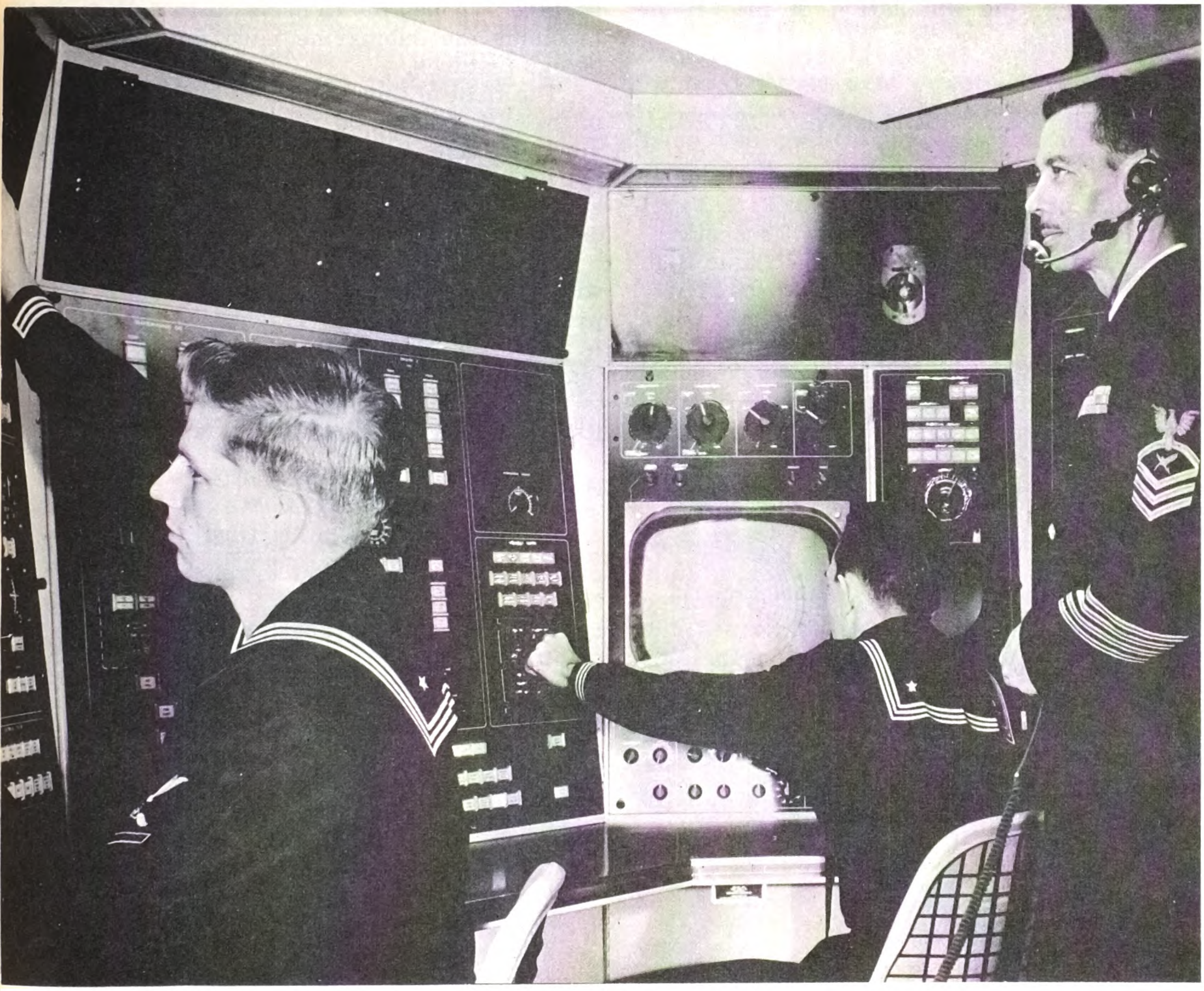


Figure 13-5.—Instructor's station, device 2F64.

station are located in the 40-foot personnel trailer. The 32-foot equipment trailer contains power supply and computer equipment and facilities for trainer repair and maintenance.

Synthetic trainers must offer pilots an opportunity to learn the characteristics of the aircraft in dangerous flight conditions which the pilot would not intentionally enter in the actual aircraft. An indication of the design problems may be gained by considering some of the peculiarities of a helicopter rotor.

As the rotor blade spins creating lift, it is free to flap up and down about a hinge at the hub of the rotor. The lift created causes the blade to flap upward. Centrifugal force, however, causes the blade to bend downward, and it seeks a point where the two forces are balanced. In hovering flight, a helicopter rotor assumes the shape of a cone. This shape is changed radically in the case of forward flight. In addition to spinning and flapping, the rotor blade changes pitch, angle of attack, and relative horizontal speed continuously throughout its cycle of rotation. Another factor which must be considered is the fact that no two points along the blade are moving at the same speed. During flight, points along the blade can vary in speed from actually negative to Mach 0.0. By regarding the rotor as many airfoils, which are continuously changing characteristics, the simulation of the SH-3A rotor is achieved.

BASIC HIGH SPEED SUBMARINE CONTROL TRAINER

Training of submariners at the U. S. Naval Submarine School at New London, Connecticut, is aided by the training device, the Basic High Speed Submarine Control Trainer, device 21B56. The trainer provides modern joystick (submarine) control with the increased sensitivity and movement responses found to be associated with the control of high speed submarines. Although intended to be used for a particular class of submarine, the trainer's versatility lends it for adaptation with any modern subsurface vessel.

The TD is responsible for the maintenance and operation of the trainer. However, to fully understand the operation and principles involved in the control and handling of submarines, the TD must have a knowledge of the basic principles of submarines.

SUBMARINES

The submarine is a ship that is built to operate chiefly below the surface of the water. It must also be capable of operating on the surface. To be able to perform in both of these mediums the submarine must possess unusual design features.

The first of these features is the possession of ballast tanks and the means to take on or eject ballast from them. In doing this, the buoyancy of the ship is adjusted to make it capable of operating on the surface or at the depth level desired. The second feature is proper construction of the hull and tanks, not only to withstand pressures but also to provide for the proper distribution of weights so that the ship is stable at all operating conditions. The third feature is the inclusion of the proper means to propel and control the submarine as it makes its way through the water.

Buoyancy

Buoyancy is generally understood to be that property of a body that enables it to float on the surface of a liquid or in a fluid. Buoyancy is the upward force exerted on the immersed or floating body which equals the weight of the fluid it displaces. This theory is illustrated in figure 13-6.

A sphere of aluminum and one of cast iron, each 10 inches in diamter (fig. 13-6), are weighed in air and then immersed in water. The aluminum sphere weighs approximately 48 pounds, and the

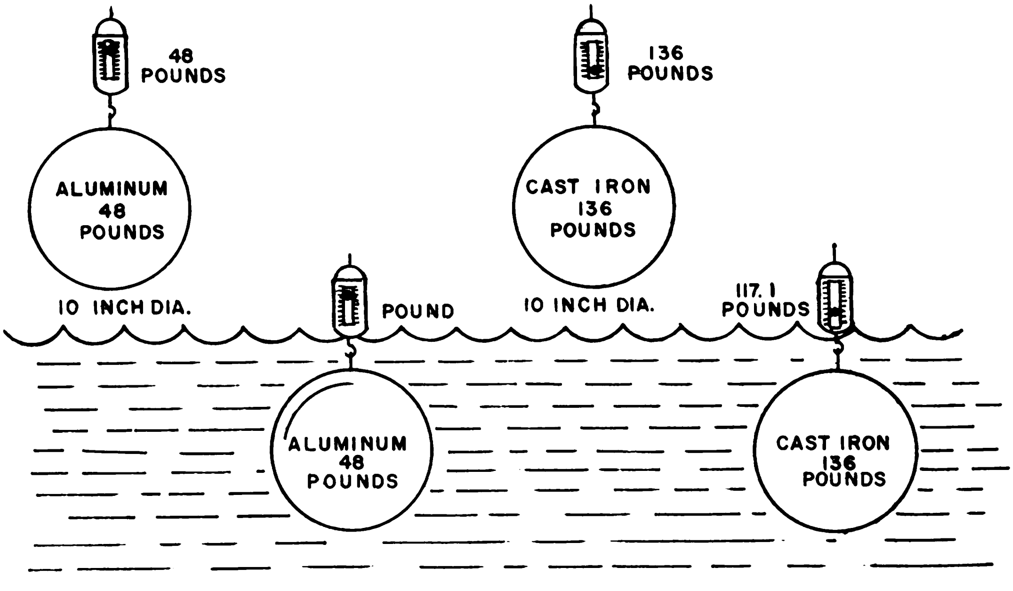


Figure 13-6.—Buoyancy depends on volume.

cast iron sphere 136 pounds. When the spheres are lowered into the water, the scale reads 29.1 pounds for the aluminum, and 117.1 pounds for the cast iron. Notice that the difference or change in weight of each sphere is 18.9 pounds. This illustrates that the buoyancy, or upward force of the displaced water, is the same in both cases and is independent of the weight of the immersed body.

The buoyancy of a submarine is also dependent on the volume of the displaced water and it is controlled by varying the volume of displacement as illustrated in figure 13-7.

Figure 13-7 (A) represents a submarine on the surface. Its main ballast tanks are filled with air. The displaced water, represented by the area within the heavy line, equals the weight of the submarine.

Figure 13-7 (B) represents a submerged submarine. Water has been admitted to the main ballast tanks expelling the air. The displaced water is now represented by the area within the heavy circle. The overall weight of the submarine is not changed, but the submarine may be submerged because the volume of displaced water has been reduced and the weight of the displaced water is now the same as (or less than) the weight of the submarine.

CENTER OF BUOYANCY.—The center of buoyancy is the center of gravity of the displaced water or the location of the upward or buoyant force. It is the geometric center of volume of the object displacing the water. The center of buoyancy should not be confused with the center of gravity of the immersed or floating body. The center of gravity is the effective center of all the weights in a ship. The total weight acts downward on the ship as if it were concentrated at the center of gravity. These two centers are indicated as B and G, respectively, in figure 13-7.

STATES OF BUOYANCY.—By definition, buoyancy is the upward force exerted on a floating or immersed body, and is independent of the weight of the body. The state of buoyancy refers to the ratio between the weight of the body and the weight of the displaced fluid. In the case of submarines, the displaced fluid is sea water. Three states of buoyancy are considered: positive, neutral, and negative buoyancy.

Positive buoyancy exists when the weight of the body is less than the weight of an equal volume of the displaced fluid.

Neutral buoyancy exists when the weight of the body is equal to the weight of an equal volume of the displaced fluid. A body in this state remains suspended, neither rising nor sinking, unless acted upon by an outside force. Submarines operate on the principle of neutral buoyancy when submerged. In this condition the weight of the submarine is opposed by an equal buoyant force permitting the submarine, theoretically at least, to lie at rest submerged. Not only must weight and buoyant forces be equal, but to maintain the submarine on an even keel,

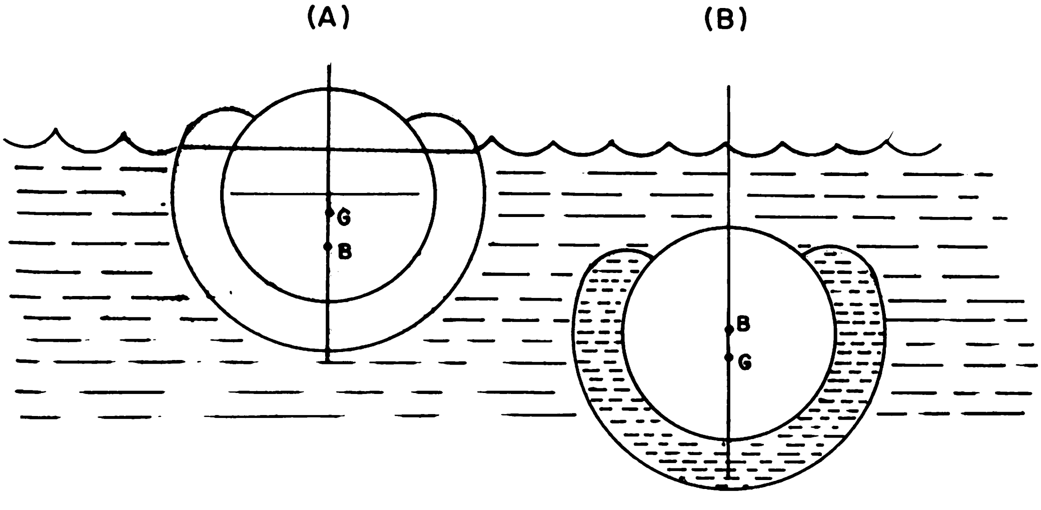


Figure 13-7.—Volume of displacement is changed.

they must be in the same longitudinal position. This condition must be maintained in sea water of varying density and in different conditions of submarine loading. For the operating submarine this is accomplished by regulating the amount of water in the variable ballast tanks. These tanks are used for changes in weight and moment necessary to obtain the desired buoyancy conditions. For this purpose they are located at the ends of the submarine (forward and aft trim tanks) and amidships (auxiliary tanks). Water can be transferred from one of these tanks to another, flooded from the sea, or pumped overboard.

Negative buoyancy exists when the weight of the body is greater than the weight of an equal volume of the displaced fluid and the body sinks.

Theoretically, a submarine is designed with its main ballast tanks of such volume that when they are flooded, the ship is in the state of neutral buoyancy. Negative buoyancy is gained by flooding the negative tank.

Stability

Stability is that property of a body that causes it, when disturbed from a condition of equilibrium, to develop forces, or moments, that tend to restore the body to its original condition.

Equilibrium is a state of balance between opposing forces and may exist in three states; stable, neutral, and unstable.

Stable equilibrium is that property of a body that causes it, when disturbed from a condition of equilibrium, to develop forces or moments that tend to restore it to its original condition. For example, a ship is stable if by putting an angle on the ship, forces are established which act to reduce the angle. When a floating body is in stable equilibrium, its center of gravity and its center of buoyancy are in the same vertical line.

Neutral equilibrium exists when a body remains in its displaced position after a force that placed it in such position is removed.

Unstable equilibrium exists when a body tends to continue movement after a slight displacement.

These three states are illustrated in figure 13-8. A cone resting on its base may be tipped in any direction, within limits, and will return to its original position when released. A cone lying on its side may be rolled on its surface and will remain in its displaced position. A cone may be balanced on its point and remain in equilibrium but when disturbed, will be in unstable equilibrium.

The two conditions, buoyancy and stability, are so closely related and interdependent when considered in connection with submarines that they must be discussed together.

The purpose and use of ballast tanks to control the buoyancy and stability of a submarine can be seen from the following example:

Assume that a 1,500-ton submarine is preparing to make a dive to and maintain periscope depth. The ship has a surface displacement of 1,523 tons and draws 14 feet of water. When fuel oil and lube oil tanks are completely filled, it draws 15 feet 6 inches of water. With

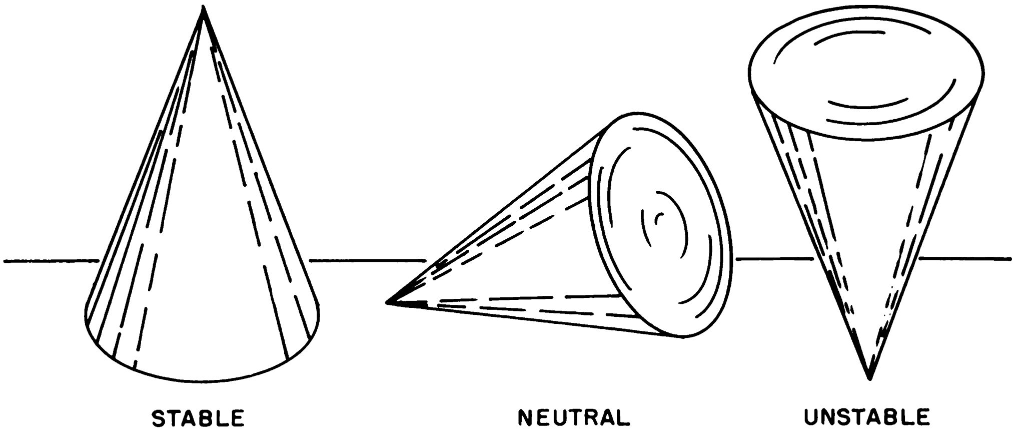


Figure 13-8.—States of equilibrium.

the designed weight plus oil, stores, and crew the submarine weighs 1,816 tons. The problem is to take on enough weight so that the ship will submerge to the proper depth and remain there. The weight to be taken on is water, and it is flooded into ballast tanks. The main ballast tanks are located along the center portions of the ship between the inner pressure walls and the outside hull. They account for the greater percentage of the water ballast normally carried. The aft trim tank, forward ballast tank, and bow buoyancy tank are descriptive of their location.

To start the submarine submerging the entrapped air is vented out of the ballast tanks as the water flows in. First, the large tanks (main ballast tanks) are flooded. These tanks hold approximately 393 tons of sea water. The submarine now displaces 2,109 tons and draws approximately 22 feet of water. The main deck is not awash since it is still approximately 2 feet from waterline to deck and the ship still has plenty of positive buoyancy. Since the bow buoyancy tank vent has been open during this operation, added weight is taken on as the tank fills with water. This gives a new displacement of 2,127 tons.

Simultaneously with the flooding of the bow buoyancy tank another special tank, called the safety tank, is flooded. This tank holds 23 tons of water, giving a total displacement of 2,150 tons and a draft of 24 feet. The decks are just awash, and some positive buoyance is still retained although the submarine is approaching a condition of neutral buoyance. Two things remain yet to be done; to take on additional weight, and to distribute this remaining weight so that fore-and-aft and athwartship balance is maintained.

This additional weight is added to the variable ballast tanks (located throughout the ship) and is distributed throughout the variable tanks by the trim system. With the ship in this condition, approximately 69 tons of water is added to the variable tanks, and the ship submerges to the proper depth. The ship is now in a state of neutral buoyancy and is balanced. At this point, any additional ballast taken on causes the submarine to sink, and any ballast removed causes it to rise.

Neutral buoyancy and stability are conditions that are very difficult to maintain in practice unless the force of buoyancy is assisted by some outside force. On a submarine, this assistance is provided by the planning action of bow and stern planes (similar to the ailerons and elevators on an aircraft) as the ship is propelled through the water.

If the trim adjustment is reasonably accurate, the ship can be easily controlled by its planes and speed. For minor depth changes, the submarine can plane up or down with the bow and stern planes. To increase depth rapidly, negative ballast tanks are flooded giving the ship negative buoyancy. This added weight, normally accompanied with an increase in speed and dive angle, forces the submarine down faster than can be done by planing action alone. After the initial downward impetus is gained, the negative tank is blown clear of water and the ship returns to neutral buoyancy so that it can be leveled off at any desired depth. If it is desired to surface after returning to periscope depth, bow buoyancy tank and main ballast tanks are blown to restore positive buoyancy. The variable tanks are not blown as these tanks control the trim of the submarine, and as long as they contain the adjusted weight of water, the ship is in a condition of diving trim.

Forces Acting on a Submerged Submarine Underway

A submarine at rest is acted upon by hydrostatic forces and moments due to weight and buoyancy. In addition, when a submarine moves through the water it is also acted upon by hydrodynamic forces. The hydrodynamic forces may be divided into four groups as follows:

1. Forces caused by hull form and bubble.
2. Forces caused by angle of tilt on the diving planes.
3. Vertical forces caused by propeller shaft thrust.
4. Vertical forces caused by turning in a horizontal plane.

All of the dynamic forces increase with an increase in speed of the submarine. It has been determined that the forces increase with the square of the speed. For example, the forces under similar conditions acting on a submarine making 3 knots would be multiplied 25 times if the speed were increased to 15 knots.

Forces caused by the hull form and bubble are by far the greatest in effect on the submarine. The upsweep of the forward end of the hull presents a planing surface (fig. 13-9) which has a tendency to rotate the bow in a rise direction.

The conning tower fairwater and any other vertical structure (fig. 13-10) causes a dragging effect which tends to rotate the bow upward.

The deck and bottom surfaces present a very large planing surface whenever the submarine presents other than a zero angle to the water moving past it (fig. 13-11). The resultant of the forces caused by the deck or bottom surfaces are such as to force the submarine deeper if a down angle is presented, or shallower if an up angle is presented. These forces are three to five times greater than the forces caused by the use of the diving planes.

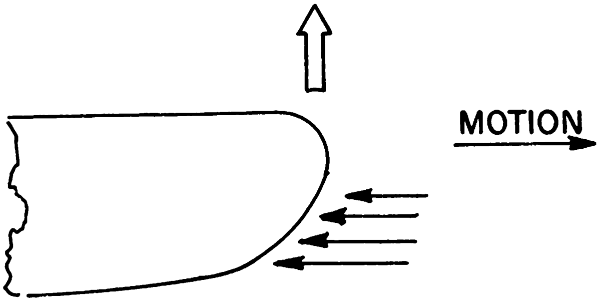


Figure 13-9.—Forces caused by hull form.

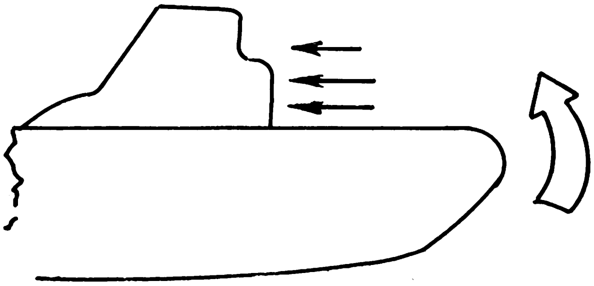


Figure 13-10.—Vertical structure effect.

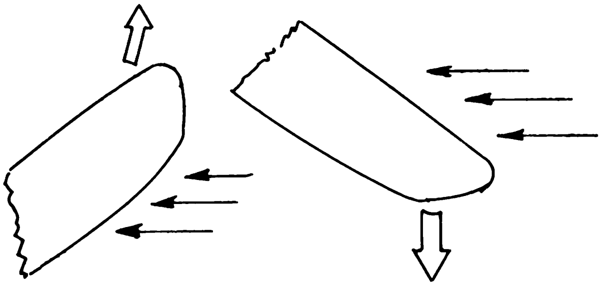


Figure 13-11.—Deck and bottom effect.

The dynamic forces acting on a diving plane moving through the water are similar to the forces acting on an aircraft wing moving through the air. A vertical and a horizontal component are present in some degree at all times. The vertical component may be up or down. The horizontal component is always opposed to the horizontal direction of motion and is small when compared to the horizontal propulsion force.

When the diving plane is at 0° tilt (fig. 13-12), the vertical component is negligible and no planing force is generated.

When the diving plane is tilted from 0° toward a rise angle (upward), the vertical component increases greatly. The vertical component of force in the situation shown in figure 13-13 tends to push upward at the site of the plane.

When the diving plane is tilted to a down angle, the vertical component is in a downward direction (fig. 13-14) tending to push down at the site of the plane.

Considering the submarine to be a lever, the force on a tilted plane will, in addition to forcing upward or downward at the site of a plane, tend to rotate the submarine about the center of buoyancy (fig. 13-15).

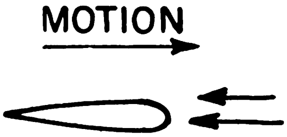


Figure 13-12.—Diving plane at 0°.

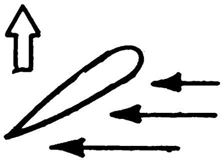


Figure 13-13.—Upward vertical component.

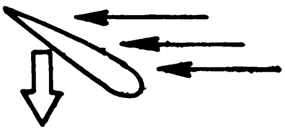


Figure 13-14.—Downward vertical component.

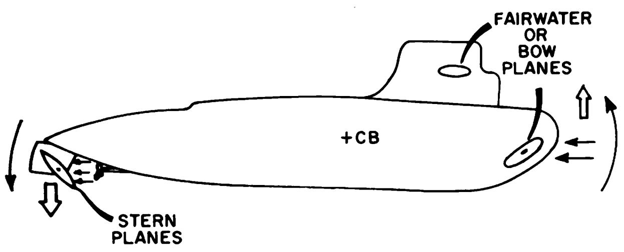


Figure 13-15.—Submarine control planes.

STERN PLANES.—The stern planes (fig. 13-15) are mounted just aft of the propellers in the discharge stream. Their primary effect is rotational. Therefore, the stern planes are used to control the angle on the ship. In addition, since the stern planes are used to maintain the bubble (horizontal plane), they are a primary source of information on where the ship is out of trim.

BOW PLANES.—The bow planes on diesel-electric submarines are located closer to the center of buoyancy (fig. 13-15) than are the stern planes. The primary effect of the bow planes is in the vertical direction whether up or down.

FAIRWATER PLANES.—Bow planes have been eliminated on modern submarines and fairwater planes are used in their place. On nuclear attack submarines the fairwater planes are located almost directly above the center of buoyancy and therefore have almost no effect on the angle of the ship. The fairwater planes on the FBM classes are slightly forward of the center of buoyancy (fig. 13-15) and their use does effect the angle of the ship. In both cases an angle on the fairwater planes will cause the ship to change depth without changing its angle.

Vertical force is exerted on the ship by the effect of the propeller shaft thrust. On twin screw ships the propeller shafts are inclined downward from the horizontal center line about 1 1/2°. Propeller shaft thrust is directed below the center of buoyancy; therefore, an upward force is caused by the propeller shaft thrust which tends to drive the bow upward (fig. 13-15) when the submarine is traveling through the water on an even keel. The vertical force is small at low speeds and therefore does not effect the handling of the submarine to any great extent.

When a submarine changes course while cruising submerged, water flows at an angle across the hull. As the cross flow passes the fairwater, an increased pressure area is created on top of the hull aft of the fairwater. This increased pressure area tends to force the stern down. The downward force may be countered by using dive angle on the stern planes.

Depth Control

From the foregoing discussion of the forces acting on a submarine, it can be seen that the control and handling of a submarine is a complex problem. The actions of several people must be coordinated to achieve control. The diving officer must correlate the actions of several stations and perform his job of calling for specific actions to maintain control of the submarine. His actions aid the conning officer in maneuvering the ship. The operators of numerous controls and control panels are required to aid the diving officer to successfully bring the ship to the desired depth and maintain the depth.

The hydrodynamic aids which help the diving officer are speed, hull angle (bubble), angle on the bow and stern planes, and the ballast tanks. Each of these are controlled from various stations in the ship. The individual manipulations and required coordinated actions of the various stations present a training problem resolved only through concentrated practice. Training devices such as 21B56 are aiding in this training problem.

DEVICE 21B56

The basic high speed submarine control trainer consists of a training cabin and gimbal assembly, an analog computer, an electro-hydraulic servomechanism system, an instructor station, and a chart type dual channel recorder.

Training Cabin

The movable cabin (fig. 13-16) contains stations for two trainees, an inboard primary station and an outboard primary station. These occupy the major floor area in the aft part of the cabin. The elevated instructor's station is at the rear, providing observation of the bulkhead indicators and student operation. In addition, standing room is provided for three observers.

Each trainee station includes a floor mounted control column, a combined instrument panel, and a training seat equipped with a lap type safety belt.

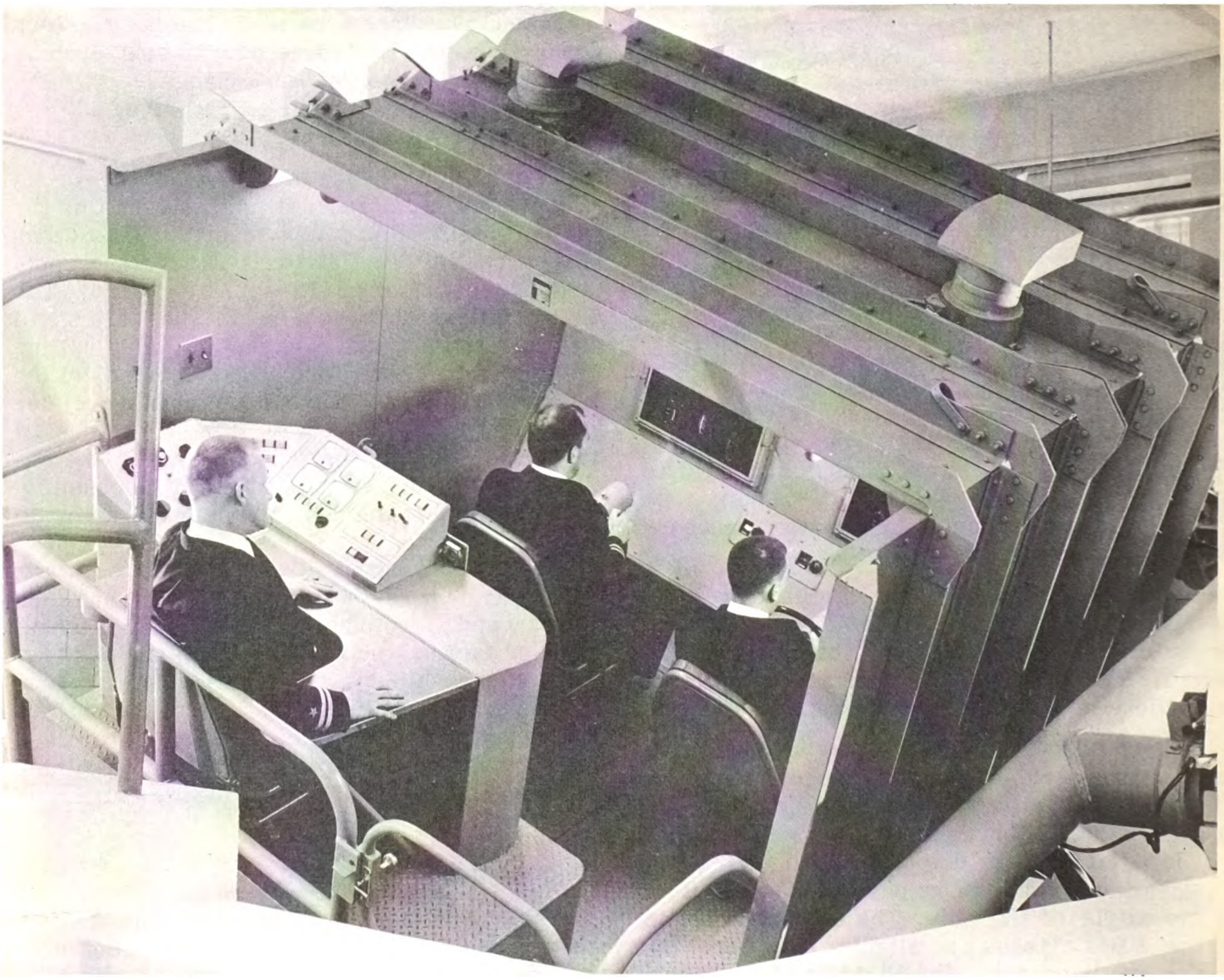


Figure 13-16.—Training cabin, device 21B56.

The entire student environment has been designed for optimum realism. All the required instruments are provided for operation of the simulator by the two trainees.

Instructor's Station

The instructor's station is situated at the aft end of the cab and to the left of center. A console located in front of the instructor provides instrument and control panels. The instruments and control switches on each panel are grouped according to function and are designated as the trainer control, submarine control, instrument failures, and the scoring panel.

Analog Computer

The computer is a fully transistorized, general purpose, analog computer. The front face of the computer is divided into three rows of computing elements and various interconnecting terminations known as a patch panel. The patch panel connects the individual building blocks of the computer and affords the means for setting up the equations of motion to be solved. These mathematical relationships arise by virtue of the substitution of an electromechanical system and training analogy for a physical situation. The physical system referred to is one of an operational submarine in a regular maneuver.

The computer solves the mathematical equations of motion of the submarine and uses the solutions to these equations to activate an electrohydraulic system which positions a training cab in the same manner as an operational submarine should be positioned.

In this simulation, controlling motions which would normally control the motions of the submarine are used to control the inputs to the analog computer. The computer's output is used to control panel indications as well as the position of the trainer as would be indicated on an operational submarine. Thus, an expensive operation is replaced with an inexpensive simulation system which is able to accomplish the same results.

The inputs to the analog computer consist of control motions of rudder, fairwater planes, and stern planes. Ship's status inputs of depth, course, speed, weight, moments, and the student scoring system are also inputs to the computer.

The outputs of the analog computer consist of signal voltages to the various indicating instruments and voltage levels to the hydraulic system for positioning of the hydraulic actuators. The actuators provide pitch and roll motions to the trainer cab. Voltage outputs are also provided to the permanent chart type strip recorder for permanent records of trainer operation.

Electrohydraulic System

The training cabin is caused to pitch and roll by means of two positional servomechanism systems powered by a common hydraulic supply system. The major components of this system are the motor-driven hydraulic pump, oil reservoir, oil cooler, flow regulator, amplifier, pitch and roll actuating cylinders, feedback potentiometers, and various relief, solenoid, and pressure valves.

Input commands, consisting of signal voltages representing pitch and roll motion, evolve from the equations of motion solved by the analog computer. These commands are initiated by the trainee control columns. These pitch and roll signals are command inputs for the electrohydraulic positional servos which orient the training cabin to the desired position.

When operating, the 30-horsepower motor and pump combination unit supplies constant flow deliveries of 21 gallons per minute at 2,000 psi outlet pressure from the reservoir to the pump relief valve. The pump relief valve maintains a constant pressure. When pressure is built up to the desired setting, the oil is discharged through the return connection of the valve to the reservoir.

Another function of the relief valve is to drop the system pressure when it is desirable. This is accomplished through venting ports in the relief valve. Venting causes the pressure to drop and allows the valve to open fully, resulting in minimum output pressure from the pump.

System Operation

The training problem starts with a determination of the goals to be achieved. These tasks are then set into the trainer by the instructor in the form of initial inputs to the computer.

Operation of the controls at the steering and diving stations of the trainer results in signal voltages (calling for control plane motion) being sent to the computer. The computer solves the equations for the particular submarine based on the inputs and the initial condition settings. These solutions are dependent only upon the inputs at any certain time plus the characteristics of the submarine being simulated.

The solution, as an output from the computer, goes to several places. The solution (voltage changes) is supplied as inputs to the hydraulic system of the trainer. The hydraulic system converts these voltage inputs into motion of pitch and roll of the training cab to give the trainee the actual feel of motion. The voltage outputs from the computer are also sent to the instruments on both of the trainee's stations. The trainees make use of the visual results to continue in their control of the submarine during the maneuver being executed. Likewise, the instructor may use these visual indications as a method of subjectively scoring the maneuver being executed.

The output voltages from the analog computer go to the metered scoring system on the instructor's console and to the permanent chart recorder. The metered scoring system compares the actual or computer solutions with the prescribed limitations originally established by the instructor. The results of this scoring system may then be used as an objective method of scoring the trainees.

The outputs of the analog computer may also be permanently recorded on the chart type ink recorder. This permanent record then serves as a guide for the student or instructor in any critique given after the actual operation of the equipment.

FBM WEAPON SYSTEM TRAINER

Operational team training is required for the personnel assigned to the fleet ballistic missile (FBM) submarines. Operating on the two-crew concept means that it is impractical for the crews to be able to maintain proficiency by reliance on training cruises only. With the submarine in transit, on station, or involved in a crew changeover, operational training is difficult to obtain. The changeover system however does allow the crew in off-patrol status to obtain refresher training. One of the more important aspects of refresher training is the operation team training. Other training, such as individual operator and refresher maintenance training, may also be conducted.

The very nature of the FBM submarine and its tactical mission inherently prohibits exercising many of the components and equipments through all phases of operation where personnel are involved. This is different from normal torpedo fire control problem in which it is possible to train crews at sea where torpedoes can actually be fired. Even in torpedo fire control training, the value of training simulators is recognized to provide practice of operations prior to operating the actual equipment.

The FBM team trainer, device 21A37 (fig. 13-17) is housed in a specially constructed building located at the U.S. Naval Submarine Base, New London, Connecticut. The trainer consists of two major device complexes. The first of these, referred to as the first increment, includes training for the missile control center, missile compartment, navigation control center, and ships control center of the George Washington class of FBM submarine. The second portion, or second increment, contains a complex of attack centers for the George Washington, Skate, and Thresher class of submarines. A tactical display center allows various types of submarine tactical problems involving all the individual trainer centers to operate as a complete operating force.

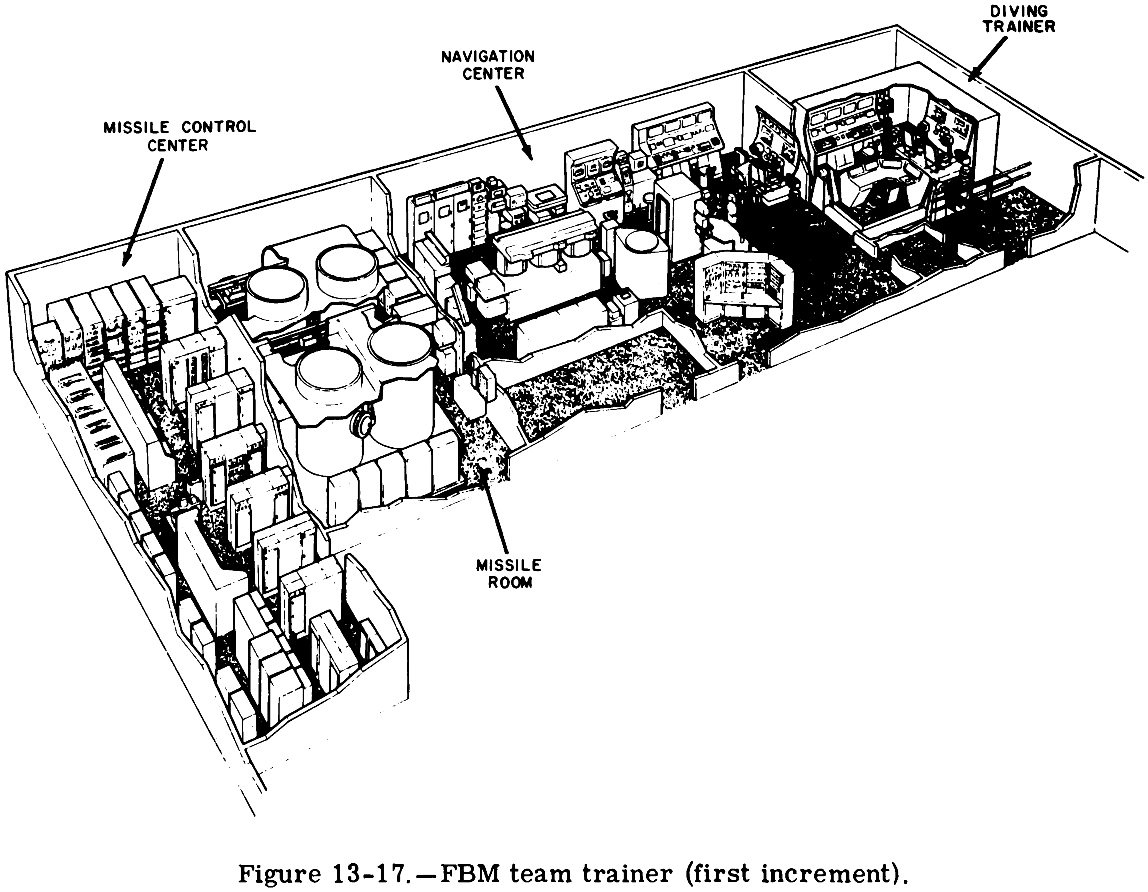


Figure 13-17.—FBM team trainer (first increment).

The missile control center (fig. 13-18) and the missile compartment provide training in the procedural and team operations for the Polaris launching and fire control systems. The complexity of the operational equipment required the simulation to be provided by a special purpose digital computer which solves the control and indicator logic of the operational systems. The training crews can maintain the various readiness conditions and countdown sequences required to launch missiles. Training device unit inputs and outputs go through logic circuitry which detects operator errors. Trainee actions and trainee errors are instantaneously indicated by light signals on the instructor's console as well as being recorded by the automatic typewriter. The instructor varies the training problem by inserting malfunctions through controls and through malfunction card readers at the instructor's console.

Unlike the missile control center, the missile room (fig. 13-19) does not approach the magnitude of its operational counterpart. It would require an extremely large room to house the three levels of the 16 missile tubes in a trainer building. To provide the necessary training, four sections of tubes are installed. Two sections simulate the upper level of the ship's missile room--one simulated section for the second level and one simulated section for the third level. The training crew can exchange guidance packages, work on the air ejection system, or make adjustments and corrections to the control system. The operation of the control panels for the missile tubes is electrically connected with the missile control center so that any malfunction occurring at the tube will display the same effect on the trainer firing sequence as it would on the operation sequences.

The navigation center provides precise information on the ship's position by means of the ships inertial navigation system. The trainer provides training in the procedural aspects of navigation rather than enabling crews to actually navigate under simulated conditions. Systems such as the type 8 and type 11 periscopes are simulated with simulated planetariums which allows the operators to obtain a celestial fix selecting from about 50 available stars. Navigational position can also be obtained with the use of electronic navigation aids. Simulated output signals from the inertial navigators allow the training crew to monitor and reset the control equipments as is done on the operational equipment. The navigation center is activated by means of a special purpose digital computer.

The attack center (fig. 13-20) contains the simulated equipment for target information. The training crew is able to detect, track, display, and identify simulated targets as they would appear in the operational equipment.

The simulation of the ship's control center (diving trainer) provides the means for training the personnel responsible for maneuvering the submarine and operating the ballast control panel. The simulating system utilizes a general purpose analog computer to control the operation of the trainer. In order to train personnel in the maneuvering and control of the submarine during the missile firing phase, the missile compensation system, which is part of the ballast control panel, is also included.

The team trainer, in addition to providing training space for individual and team training on the FBM system, provides an installation where modifications can be installed and refresher training can be conducted to keep operating personnel qualified in the latest changes to the operational equipment.

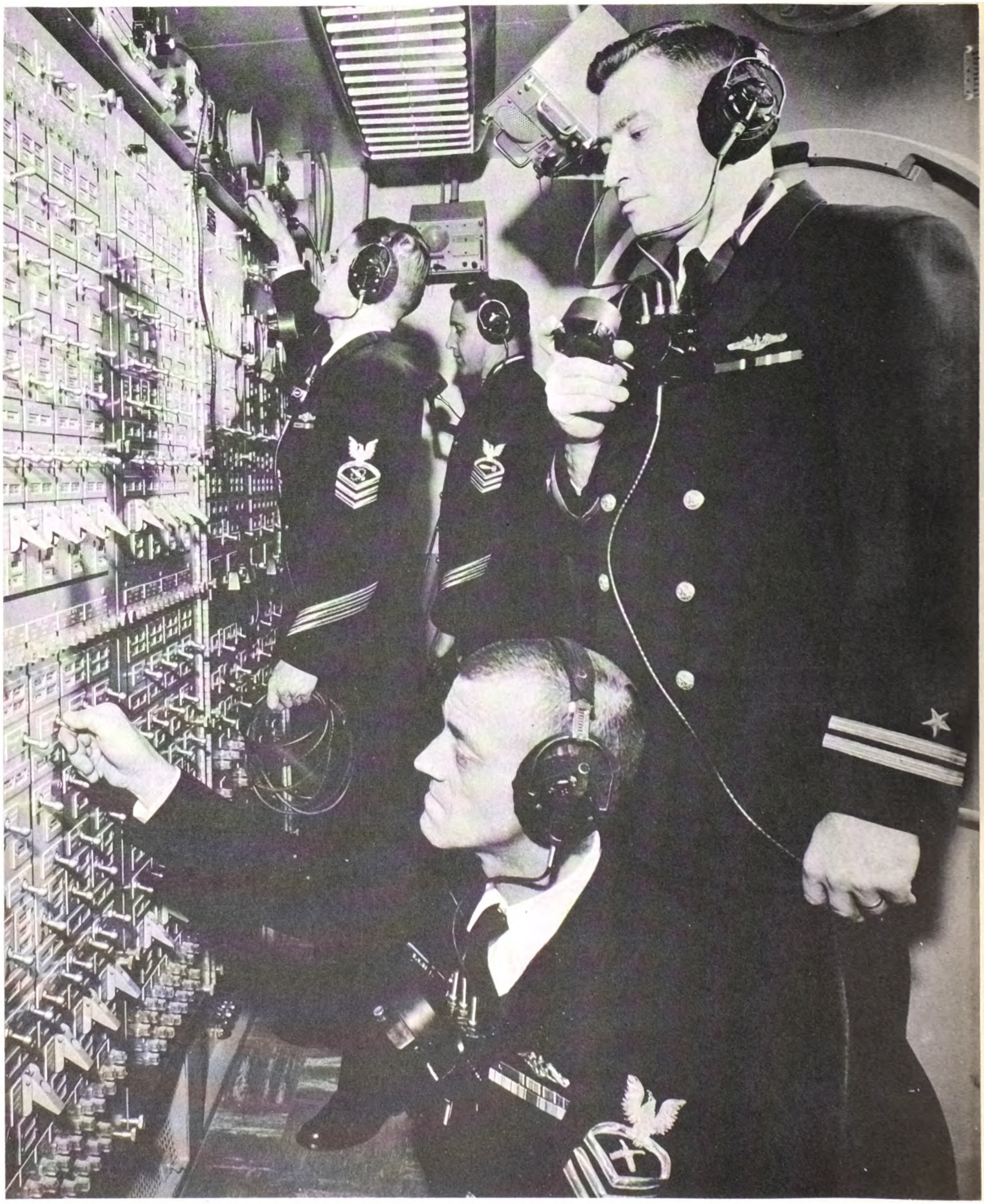


Figure 13-18.—Supervisor's console in missile control center.

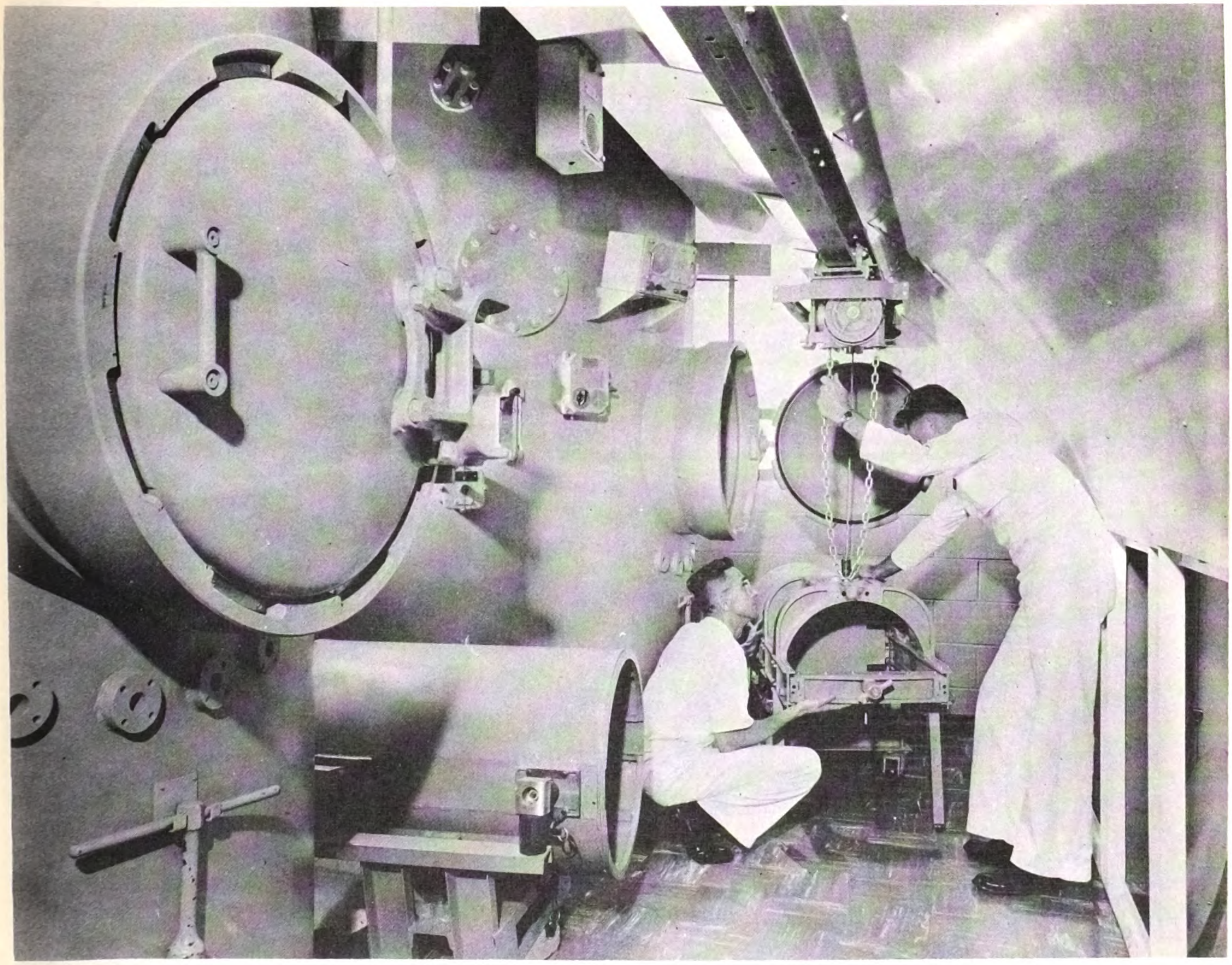


Figure 13-19.—Missile room.

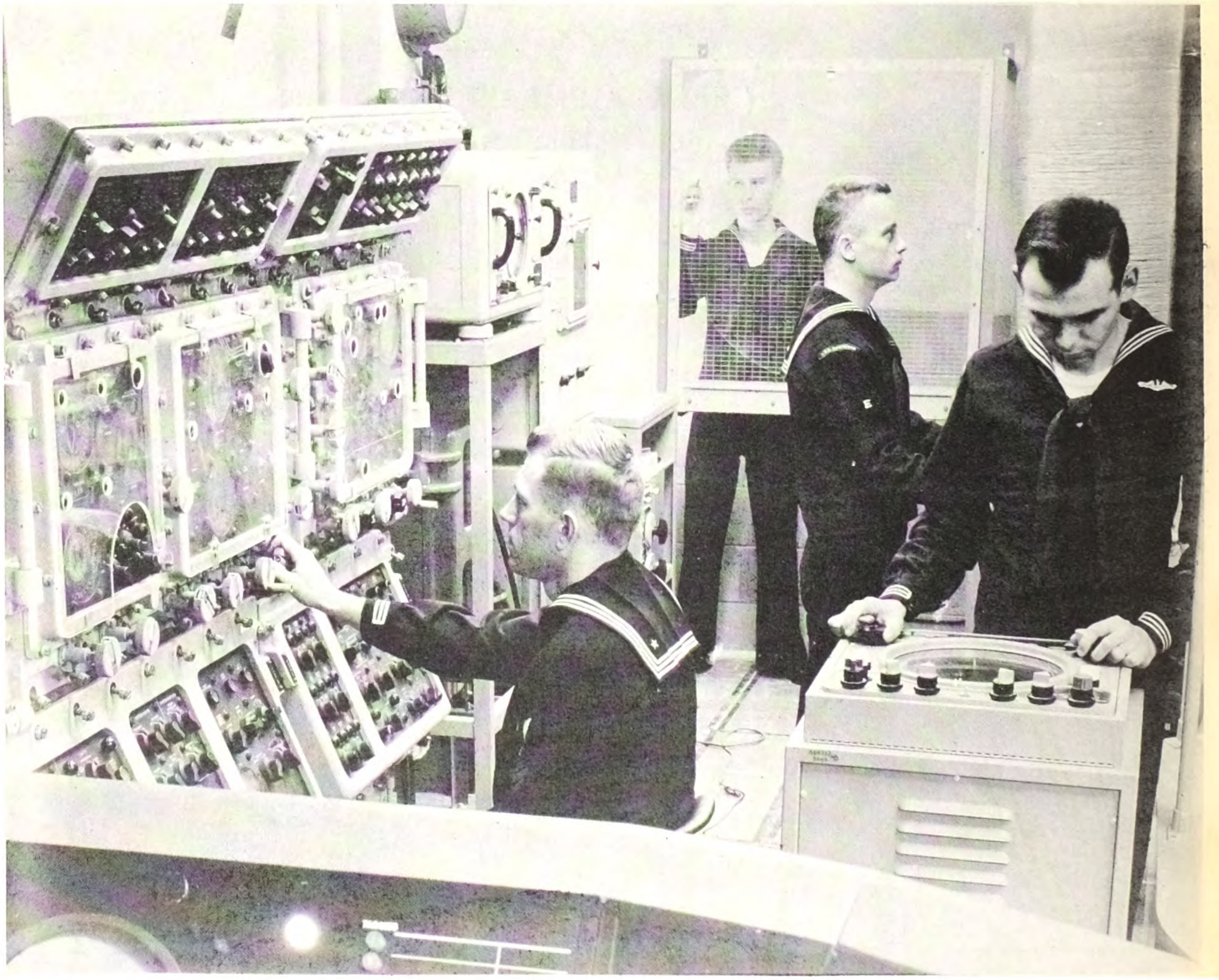


Figure 13-20.—Attack center No. 1 (Mk 112 fire control system).

APPENDIX I

GREEK ALPHABET

Name	Capital	Lower case	Designates
Alpha	Α	α	Angles.
Beta	Β	β	Angles, flux density.
Gamma	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon	Ε	ϵ	Base of natural logarithms (2.71828).
Zeta	Ζ	ζ	Impedance, coefficients, coordinates.
Eta.	Η	η	Hysteresis coefficient, efficiency.
Theta	Θ	θ	Phase angle
Iota	Ι	ι	
Kappa	Κ	κ	Dielectric constant, coupling coefficient, susceptibility.
Lambda	Λ	λ	Wavelength.
Mu	Μ	μ	Permeability, micro, amplification factor.
Nu	Ν	ν	Reluctivity.
Xi	Ξ	ξ	
Omicron	Ο	ο	
Pi	Π	π	3.1416
Rho	Ρ	ρ	Resistivity.
Sigma	Σ	σ	
Tau	Τ	τ	Time constant, time-phase displacement.
Upsilon	Υ	υ	
Phi.	Φ	ϕ	Angles, magnetic flux.
Chi.	Χ	χ	
Psi.	Ψ	ψ	Dielectric flux, phase difference.
Omega	Ω	ω	Ohms (capital), angular velocity (2π f).

APPENDIX II

USEFUL FORMULAS AND RELATIONS BETWEEN COMMON UNITS

Electrical and Electronic Formulas

Ohm's Law for D-C Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2 R$$

Resistors in Series

$$R_t = R_1 + R_2 + \ldots + R_n$$

Resistors in Parallel

Two resistors

$$R_t = \frac{R_1 R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}$$

Capacitors in Series

Two capacitors

$$C_t = \frac{C_1 C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n}$$

Capacitors in Parallel

$$C_t = C_1 + C_2 + \ldots + C_n$$

Capacitive Reactance

$$X_c = \frac{1}{2\pi fC}$$

Inductors in Series

$$L_t = L_1 + L_2 + \ldots + L_n$$

Inductors in Parallel (Two inductors)

$$L_t = \frac{L_1 L_2}{L_1 + L_2} \text{ (No coupling between coils)}$$

Inductors in Parallel (More than two)

$$\frac{1}{L_t} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots + \frac{1}{L_n}$$

Inductive Reactance

$$X_L = 2\pi fL$$

Impedance

In an a-c circuit, the impedance (Z) in ohms is defined by the following relation

$$Z = \frac{E}{I}$$

where E is in volts and I is in amperes.

Impedance of a Series R-L Circuit

$$Z = \sqrt{R^2 + X_L^2}$$

Impedance of a Series R, C, L Circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Impedance of a Parallel Circuit (Two branches)

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

In a Series L-C Circuit

$$Z \text{ (at resonance)} = R$$

In a Parallel L-C Circuit

$$Z \text{ (at resonance)} = \frac{X_L^2}{R} = \frac{X_L X_C}{R} = \frac{L}{CR}$$

R-C Circuit Time Constants

R (ohms) × C (farads) = t (seconds)

R (megohms) × C (microfarads) = t (seconds)

R (ohms) × C (microfarads) = t (microseconds)

R (megohms) × C (micromicrofarads) = t (microseconds)

R-L Circuit Time Constants

$$\frac{L \text{ (in henrys)}}{R \text{ (in ohms)}} = t \text{ (seconds)}$$

$$\frac{L \text{ (in microhenrys)}}{R \text{ (in ohms)}} = t \text{ (in microseconds)}$$

Transformers

Voltage relationships

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

where

E_p = primary voltage

E_s = secondary voltage

N_p = primary turns

N_s = secondary turns.

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Impedance relationship

$$\frac{N_p^2}{N_s^2} = \frac{Z_p}{Z_s}$$

Synchronous speed of motor

$$\text{r.p.m.} = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

Relations Between Common Units

Length

1 meter = 10 decimeters = 100 centimeters (100 cm.) = 1,000 millimeters (1,000 mm.)

1 inch = 2.540 centimeters

1 foot = 30.48 centimeters

1 kilometer = 1,000 meters = 0.6214 mile

Volume

1 liter = 1,000 cubic centimeters (cc.)

= 61.024 cubic inches

= 1.05671 quarts

Angles

1 circumference = 360° = 2π radians

1 radian = 57.2958°

Pressure

1 atmosphere = 76 cm. of mercury

= 14.697 pounds per square inch

Power

1 horsepower (H.P.) = 33,000 foot-pounds per minute

= 550 ft.-lb./sec.

= 746 watts

1 watt = 1 joule per second

Work or Energy

1 foot-pound = 1.356×10^7 ergs

1 B. T. U. = 777.8 foot-pounds

1 kilowatt-hour = 1,000 watt-hours

Velocity

1 foot per second = 0.6818 m.p.h. = 1.097 kilometers per hour

1 m.p.h. = 0.8684 knot = 1.467 ft. per sec.

= 1.609 kilometers per hour

1 knot = 1.152 m.p.h. = 1.689 ft. per sec.

= 1.853 kilometers per hour

Mass

1 cubic centimeter (cc.) of water weighs 1 gram (gm.)

1 kilogram = 1,000 grams = 2.2046 lbs.

1 lb. = 453.59 grams

1 cubic foot of water weighs 62.4 lbs.

Temperature

	Fahrenheit (F)	Centigrade (C)	Absolute (K)
Absolute zero:	-523°	-273°	0°
Water freezes:	32°	0°	273°
Water boils:	212°	100°	373°

APPENDIX III

LAWS OF EXPONENTS

The following listings show a sequence of whole numbers and decimals expressed in the usual manner and also expressed as powers of ten. The latter method of writing numbers is often convenient when dealing with very large or very small quantities, and is frequently used in scientific work.

Number	Powers of Ten
100,000	10^5
10,000	10^4
1,000	10^3
100	10^2
10	10^1
1	10^0

Number	Powers of Ten
0.00001	10^{-5}
0.0001	10^{-4}
0.001	10^{-3}
0.01	10^{-2}
0.1	10^{-1}

To multiply two or more quantities written as powers of the same base (in this case, 10), add the exponents. In the language of algebra, the general rule for multiplication is

$$a^m \times a^n = a^{m+n}$$

For example, when multiplying 10,000 by 100, this rule is applied as follows:

$$10^4 \times 10^2 = 10^{4+2} = 10^6$$

and

$$\begin{aligned} 0.003 \times 825.2 &= 3 \times 10^{-3} \times 8.252 \times 10^2 \\ &= 24.756 \times 10^{-1} \\ &= 2.4756. \end{aligned}$$

To divide exponential quantities, subtract the exponent of the divisor from the exponent of the dividend. In the language of algebra, the rule is

$$a^m \div a^n = a^{m-n}$$

Thus,

$$10^8 \div 10^2 = 10^6$$

and

$$\begin{aligned} 3{,}000 \div 0.015 &= (3 \times 10^3) \div (1.5 \times 10^{-2}) \\ &= 2 \times 10^5 \\ &= 200{,}000. \end{aligned}$$

To raise an exponential quantity to a power, multiply the exponents. In the language of algebra,

$$(10^3)^4 = 10^{3 \times 4} = 10^{12}$$

$$2{,}500^2 = (2.5 \times 10^3)^2 = 6.25 \times 10^6 = 6{,}250{,}000.$$

Any number (except zero) raised to the zero power is one. In the language of algebra,

$$a^0 = 1.$$

This can be shown to be true by means of the rule governing division:

$$\begin{aligned} a^0 &= a^{m-m} \\ &= a^m \div a^m \\ &= 1. \end{aligned}$$

Any base with a negative exponent is equal to 1 divided by the same base with an equal positive exponent. The general rule is

$$a^{-m} = \frac{1}{a^m}$$

Thus,

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = 5\left(\frac{1}{a^3}\right) = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2 = 400$$

$$(3{,}000)^3 = (3 \times 10^3)^3 = 3^3 \times 10^9 = 27 \times 10^9.$$

To find the nth root of an exponential quantity, divide the exponent of the quantity by the index of the root. Thus, the nth root of a is $a^{1/n}$. In general, the nth root of a^m is $a^{m/n}$. To illustrate, the cube root of 64,000 can be found by the following procedure:

$$
\begin{aligned}
(64{,}000)^{1/3} &= (4^3 \times 10^3)^{1/3} \\
&= 4 \times 10 \\
&= 40.
\end{aligned}
$$

APPENDIX IV
TRIGONOMETRIC FUNCTIONS

In any right triangle, such as ABC in figure IV-1, the ratio of any two sides is determined by the values of the angles and is not dependent upon the size of the triangle. These ratios are very important in applied mathematics and have been given definite names. Six ratios are employed. By definition, these are

$$\frac{\text{opposite side}}{\text{hypotenuse}} = \frac{a}{c} = \text{sine of angle A (written sin A)}$$

$$\frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{b}{c} = \text{cosine A (written cos A)}$$

$$\frac{\text{opposite side}}{\text{adjacent side}} = \frac{a}{b} = \text{tangent A (written tan A)}$$

$$\frac{\text{adjacent side}}{\text{opposite side}} = \frac{b}{a} = \text{cotangent A (written cot A)}$$

$$\frac{\text{hypotenuse}}{\text{adjacent side}} = \frac{c}{b} = \text{secant A (written sec A)}$$

$$\frac{\text{hypotenuse}}{\text{opposite side}} = \frac{c}{a} = \text{cosecant A (written csc A)}$$

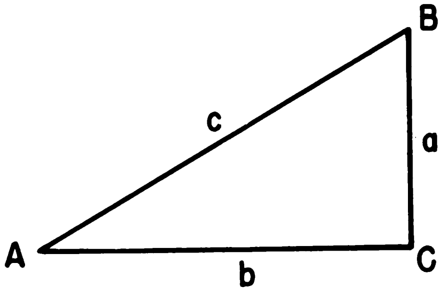


Figure IV-1.–Right triangle, ABC, with sides a, b, and c.

The values of the sines, cosines, tangents, and cotangents of angles from zero to 90 degrees are recorded in tables, an example of which is given in table IV-1. When applying these values in practical problems, two facts must be known concerning the triangle; then the remaining facts can be calculated. One of the known quantities must be a side of the triangle.

For example, in figure IV-1, if side b is 14 inches and angle A is 28 degrees, side a can be derived. In this case, tan A can be found from the table to be 0.5317. Side a is equal to 14 tan A, or 14 × 0.5317 = 7.4438 inches.

Table IV-1.–Natural trigonometric functions.

°	Sin	Tan	Cot	Cos	°
0	0.0000	0.0000		1.0000	90
1	0.0175	0.0175	57.2900	0.9998	89
2	0.0349	0.0349	28.6363	0.9994	88
3	0.0523	0.0524	19.0811	0.9986	87
4	0.0698	0.0699	14.3007	0.9976	86
5	0.0872	0.0875	11.4301	0.9962	85
6	0.1045	0.1051	9.5144	0.9945	84
7	0.1219	0.1228	8.1443	0.9925	83
8	0.1392	0.1405	7.1154	0.9903	82
9	0.1564	0.1584	6.3138	0.9877	81
10	0.1736	0.1763	5.6713	0.9848	80
11	0.1908	0.1944	5.1446	0.9816	79
12	0.2079	0.2126	4.7046	0.9781	78
13	0.2250	0.2309	4.3315	0.9744	77
14	0.2419	0.2493	4.0108	0.9703	76
15	0.2588	0.2679	3.7321	0.9659	75
16	0.2756	0.2867	3.4874	0.9613	74
17	0.2924	0.3057	3.2709	0.9563	73
18	0.3090	0.3249	3.0777	0.9511	72
19	0.3256	0.3443	2.9042	0.9455	71
°	Cos	Cot	Tan	Sin	°

Table IV-1.–Natural trigonometric functions.–Continued.

°	Sin	Tan	Cot	Cos	°
20	0.3420	0.3640	2.7475	0.9397	70
21	0.3584	0.3839	2.6051	0.9336	69
22	0.3746	0.4040	2.4751	0.9272	68
23	0.3907	0.4245	2.3559	0.9205	67
24	0.4067	0.4452	2.2460	0.9135	66
25	0.4226	0.4663	2.1445	0.9063	65
26	0.4384	0.4877	2.0503	0.8988	64
27	0.4540	0.5095	1.9626	0.8910	63
28	0.4695	0.5317	1.8807	0.8829	62
29	0.4848	0.5543	1.8040	0.8746	61
30	0.5000	0.5774	1.7321	0.8660	60
31	0.5150	0.6009	1.6643	0.8572	59
32	0.5299	0.6249	1.6003	0.8480	58
33	0.5446	0.6494	1.5399	0.8387	57
34	0.5592	0.6745	1.4826	0.8290	56
35	0.5736	0.7002	1.4281	0.8192	55
36	0.5878	0.7265	1.3764	0.8090	54
37	0.6018	0.7536	1.3270	0.7986	53
38	0.6157	0.7813	1.2799	0.7880	52
39	0.6293	0.8098	1.2349	0.7771	51
40	0.6428	0.8391	1.1918	0.7660	50
41	0.6561	0.8693	1.1504	0.7547	49
42	0.6691	0.9004	1.1106	0.7431	48
43	0.6820	0.9325	1.0724	0.7314	47
44	0.6947	0.9657	1.0355	0.7193	46
45	0.7071	1.0000	1.0000	0.7071	45
°	Cos	Cot	Tan	Sin	°

Side c = c/b × b = b sec A = b/cos A. When b is 14 and A is 28 degrees, this becomes 14/0.8829 which is equal to 15.85, approximately.

By study of the simple diagram in figure IV-1 and of the definitions, the following useful relationships can be obtained:

$$\frac{\sin A}{\cos A} = \tan A; \ \cot A = \frac{1}{\tan A}; \ \sec A = \frac{1}{\cos A};$$

$$\csc A = \frac{1}{\sin A}$$

$$\sin^2 A + \cos^2 A = 1$$

$\sin A = \cos (90 - A)$; $\cos A = \sin (90 - A)$
(Note that 90-A is angle B in the figure.)

$\tan A = \cot (90 - A)$; $\cot A = \tan (90 - A)$

Suppose that in figure IV-1, side c is made exactly one unit in length and is rotated in a counterclockwise direction beginning with angle A at 0°. The functions will then vary within the following limits as the hypotenuse varies between 0° and 90°:

sin A increases from 0 to 1.0
cos A decreases from 1.0 to 0
tan A increases from 0 to ∞
cot A decreases from ∞ to 0
sec A increases from 1.0 to ∞
csc A decreases from ∞ to 1.0

Trigonometric tables give functions of angles up to 90° only. The following rules apply for functions of angles greater than 90° but less than 180°:

$$\sin (90 + A) = \sin (90 - A)$$
$$\cos (90 + A) = -\cos (90 - A)$$
$$\tan (90 + A) = -\tan (90 - A)$$

For angles greater than 180° but less than 270°:

$$\sin (180 + A) = -\sin A$$
$$\cos (180 + A) = -\cos A$$
$$\tan (180 + A) = \tan A$$

For angles greater than 270° but less than 360°:

$$\sin (270 + A) = -\sin (90 - A)$$
$$\cos (270 + A) = \cos (90 - A)$$
$$\tan (270 + A) = \tan (90 - A)$$

APPENDIX V

FILM LIST

MN-2088-A Discipline—Giving Orders (15 minutes). This film stresses the importance of discipline and value of giving orders clearly, distinctly, and correctly. It shows the results obtained where emphasis is placed on gaining subordinates confidence and respect instead of fear. Applicable to chapters 1, 2, and 3.

MN-8165 The Importance of Personal Leadership Today (28 minutes). This film is a report of Admiral Carney's address to the naval officers of the Navy Department. The Chief of Naval Operations outlines his views on the importance of personal leadership in the U.S. Navy. He also states his views on the matter of smartness, discipline, and professional competence. Applicable to chapter 1.

MV-8730-A Strength of the Chain—On-The-Job Training (28 minutes). This film shows how on-the-job training can provide carefully trained and qualified replacements, when separation, transfer, or illness takes away key men. Applicable to chapters 1, 2, and 3.

MN-8242 Security—Your Personal Responsibility (16 minutes). This film is prepared for military personnel handling classified material. The film shows numerous situations where security leaks can occur. It makes clear that the maintenance of security in every case is a personal responsibility. Applicable to chapter 2.

MN-3425-D Supervision—Building Morale (15 minutes). This film provides situations which reveal to supervisors techniques which are useful in building and maintaining morale. Applicable to chapter 3.

MN-2104-B The Cathode-Ray Oscilloscope (23 minutes). This film explains the wide application of the scope in making instantaneous graphs of the waveform of an electronic circuit. It explains vertical and horizontal amplifiers, sweep generators, and high voltage power supplies. Applicable to chapters 4, 7, and 8.

MN-8614 Electromagnetic Cathode-Ray Tube—Theory of Operation (20 minutes). This film describes how the electrons are acted upon by the electron gun, control grid, and screen shield. The effect of a magnetic field on an electron in motion is explained, which is the basis for the action of the focus coil and deflection coil. Applicable to chapters 4, 7, and 8.

FN-8158-A Refrigeration—Introduction to Control Mechanisms (10 minutes). This film is an introduction to refrigeration control mechanisms. It shows an art schematic of a complete refrigeration system. It also describes the functions of the evaporator, compressor, condenser, and manual controls. Applicable to chapters 5 and 6.

FN-8158-B Refrigeration—Evaporator Controls (8 minutes). The controls for the evaporator of a refrigeration system are described in this film. It shows how the thermostatic switch and solenoid valve work to deliver a full flow of refrigerant to the thermal expansion valve. It illustrates how the superheat is used by the thermal expansion valve to control the flow of refrigerant into the evaporator coil. It also shows how the evaporator pressure regulator operates to release refrigerant from the evaporator to the compressor. Applicable to chapters 5 and 6.

FN-8158-C Refrigeration—Compressor Controls (28 minutes). This film describes the controls of the compressor used in a refrigeration system. It shows how the low-pressure switch turns on and off the compressor motor via the motor controller. It also shows how the safety controls protect the compressor and motor. Applicable to chapters 5 and 6.

MN-2449-A Optical Craftsmanship—Introduction to Optics (17 minutes). This film uses animation and practical examples to illustrate principles of light waves and rays. It shows how light is refracted and reflected. Also illustrated is the image formation in relation to concave and convex lenses as applied to optical instruments. Applicable to chapter 7.

MN-8342-D Target Designation System, Mark VI—Basic Television Techniques (13 minutes). The first part of the film explains the development of the square television display; parts of the cathode-ray tube; generation of the raster by interlace scanning; and generation of the horizontal and vertical sweep and retrace lines by sawtooth waves. The second part explains how the video signals form the picture. It shows the effect of blanking pulses; generation of composite video signals; generation of the picture of the tube face; and the effect of contrast and intensity controls on the video signal and display. Applicable to chapters 7 and 8.

MN-8342-E Target Designation System, Mark VI—Scan Conversion (12 minutes). This film explains the operational theory of the Graphecon tube and associated circuitry, showing video mixing capabilities, storage properties, and display illumination characteristics. Applicable to chapters 7 and 8.

MN-8342-G Target Designation System, Mark VI—TV Synchronizing Circuits (17 minutes). This film shows the basic operation of the circuits employed in a closed circuit TV for generation of TV drive and blanking pulses. Applicable to chapters 7 and 8.

MN-8342-H Target Designation System, Mark VI—TV Deflection Circuits (21 minutes). This film explains the basic circuitry and principles of operation of TV horizontal and vertical deflection circuits. It shows simple adjustments and their results. Applicable to chapter 8.

MN-8483-A Magnetic Amplifiers—Theory of Operation (18 minutes). This film presents the basic theory necessary for understanding magnetic amplifiers. It describes magnetic flux in conductors, cores, and the effect of simultaneously using d-c and a-c windings on a closed core. Applicable to chapter 9.

MN-8483-B Magnetic Amplifiers—Circuits and Applications (17 minutes). This film describes the advantages of magnetic amplifiers and gives examples of their use. It describes the effects of adding such modifications as rectifiers, crossover windings, resistors, bridge rectifiers, and feedback windings. Applicable to chapter 9.

MA-8581-C Servo Systems and Data Transmission (33 minutes). This film illustrates automatic servo and data transmission systems used as analog computers. It describes their inter-relationship and application in tracking enemy targets used in trainers. Applicable to chapters 10 and 13.

MN-8969-A Digital Computer Techniques—Introduction (16 minutes). This film presents a general introduction to digital computers. It depicts the various uses of digital computers. Applicable to chapters 11 and 12.

MN-8969-B Digital Computer Techniques—Computer Logic, Part I, Binary Numbers (12 minutes). This film defines logic as applied to digital computers. It shows how the binary number system compares to the decimal system. Applicable to chapters 11 and 12.

MN-8969-C Digital Computer Techniques—Computer Logic, Part II, Logic Elements (16 minutes). This film presents a fundamental explanation of digital computer logic. It defines the graphic symbols used in logic. Applicable to chapters 11 and 12.

MN-8969-D Digital Computer Techniques—Computer Units (25 minutes). This film describes the major units contained in digital computers. Applicable to chapters 11 and 12.

MN-8969-E Digital Computer Techniques—Logic Element Circuits (17 minutes). This film describes the basic circuits contained in the logic function of a digital computer. It presents typical AND, OR, and NOR circuits and depicts their method of operation. Applicable to chapters 11 and 12.

MN-8969-F Digital Computer Techniques—Programming (14 minutes). This film presents the units required to insert and remove information used with a digital computer. It describes the various methods of controlling a digital computer. It also presents methods of preparing a computer program. Applicable to chapters 11 and 12.

MN-8725 Management Improvement—It's Your Business (24 minutes). This film employs the animation technique to show that good management is an effective use of men, money, materials, and facilities. Applicable to chapters 12 and 13.

MN-8479-G Transistors—Servicing Techniques (20 minutes). This film presents the problems encountered when maintaining circuits in which transistors are installed. It describes the use of the heat sink and desoldering of transistors from printed circuits. Applicable to chapter 12.

MN-9460-B Electronics—Modules (14 minutes). This film describes the construction of printed boards and components used in miniaturized circuits. Applicable to chapter 12.

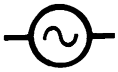
MN-19-A Submarine Training—Physical Principles (11 minutes). This film defines Arthimede's Law of Buoyancy which explains negative, neutral, and positive buoyancy. It describes how buoyancy is obtained in a submarine, together with factors governing fore and aft balance and transverse stability. Applicable to chapter 13.

MN-8427 Automatic Depth-Keeping Control System for Submarines—Principles of Operation (16 minutes). This film shows the principles of the depth-keeping control system for submarines. Components are simplified to explain how the depth and angle errors are sensed and utilized to actuate the bow and stern planes to control the submarine. Applicable to chapter 13.

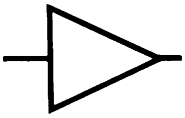
APPENDIX VI

ELECTRONIC SYMBOLS

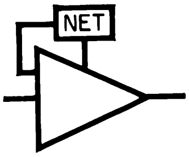
A-C SOURCE



AMPLIFIER

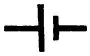


TRIANGLE POINTED IN DIRECTION OF TRANSMISSION

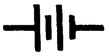


AMPLIFIER WITH EXTERNAL FEEDBACK PATH

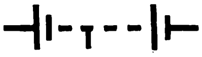
BATTERIES



ONE CELL



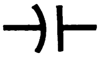
MULTICELL



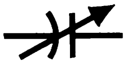
TAPPED MULTICELL

(LONG LINE IS ALWAYS POSITIVE)

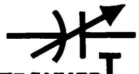
CAPACITORS



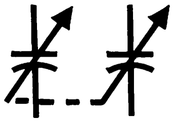
FIXED



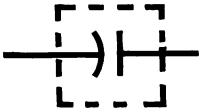
VARIABLE



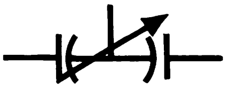
TRIMMER



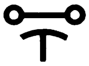
GANGED



SHIELDED



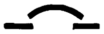
SPLIT-STATOR



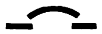
FEED-THROUGH

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

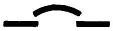
CIRCUIT BREAKERS



SWITCH

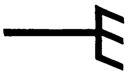


PUSH-PULL



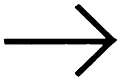
PUSH

CHASSIS CONNECTION

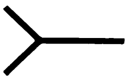


(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

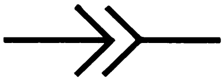
CONNECTORS



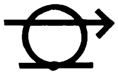
MALE
(PIN CONTACT)



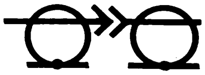
FEMALE
(SOCKET CONTACT)



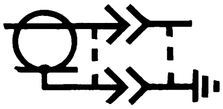
ENGAGED
(PIN-TO-SOCKET)



COAXIAL
(MALE)



COAXIAL CONNECTORS
MATED

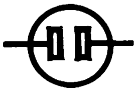


COAXIAL CONNECTED
TO SINGLE CONDUCTOR

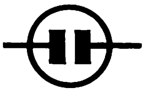
THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.

Figure VI-1

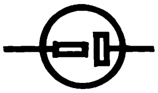
CONNECTORS, POWER



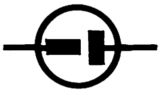
NON POLARIZED, FEMALE CONTACTS (2-CONDUCTOR)



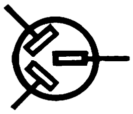
NON POLARIZED, MALE CONTACTS (2-CONDUCTOR)



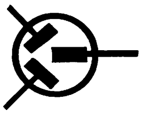
POLARIZED FEMALE CONTACTS (2-CONDUCTOR)



POLARIZED MALE CONTACTS (2-CONDUCTOR)



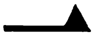
POLARIZED FEMALE CONTACTS (3-CONDUCTOR)



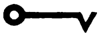
POLARIZED MALE CONTACTS (3-CONDUCTOR)

CONTACTS

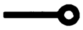
SWITCH



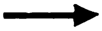
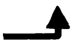
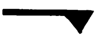
MOMENTARY SWITCH



LOCKING

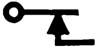


NONLOCKING

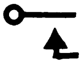
 OR  OR 

FOR JACK, KEY, RELAY, ETC.

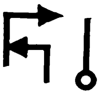
CONTACT ASSEMBLIES



CLOSED CONTACT (BREAK)

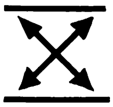


OPEN CONTACT (MAKE)

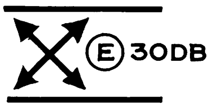


MAKE BEFORE BREAK

COUPLERS, DIRECTIONAL



GENERAL

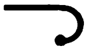


E PLANE APERTURE COUPLING, 30 DB TRANSMISSION LOSS

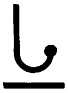
COUPLING

GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.

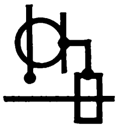
COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).



COUPLING BY LOOP TO SPACE

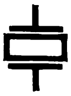


COUPLING BY LOOP TO GUIDED TRANSMISSION PATH



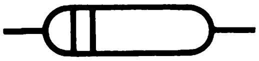
COUPLING BY PROBE FROM COAXIAL TO RECTANGULAR WAVEGUIDE WITH DIRECT-CURRENT GROUNDS CONNECTED

CRYSTAL UNIT

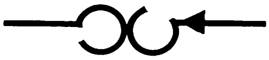


QUARTZ CRYSTAL; PIEZOELECTRIC CRYSTAL UNIT.

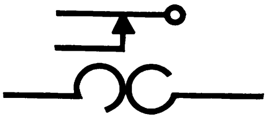
DELAY FUNCTION



ELEMENT, THERMAL

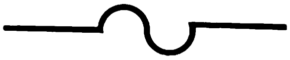


FLASHER; THERMAL CUTOUT



THERMAL RELAY WITH NORMALLY CLOSED CONTACT.

FUSE



GROUND

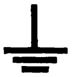
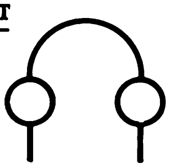
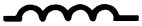


Figure VI-2

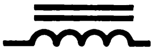
HEADSET



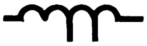
INDUCTORS



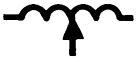
GENERAL



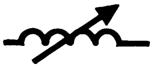
MAGNETIC CORE



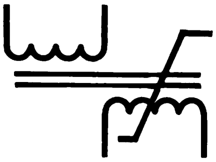
TAPPED



ADJUSTABLE

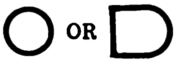


ADJUSTABLE OR CONTINUOUSLY ADJUSTABLE

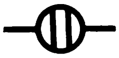


SATURABLE CORE REACTOR

LIGHT, INDICATING



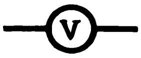
INDICATING, PILOT, SIGNALING OR SWITCHBOARD PILOT LIGHT, GENERAL.



JEWELLED INDICATOR OR WARNING LIGHT.

A LETTER MAY BE ADDED WITHIN A SYMBOL TO INDICATE A CHARACTERISTIC OR COLOR

METERS



A - AMMETER

CRO - OSCILLOSCOPE

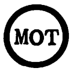
G - GALVANOMETER

MA - MILLIAMMETER

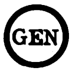
OHM - OHMMETER

V - VOLTMETER

MOTORS AND GENERATORS

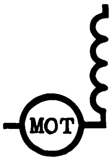


MOTOR

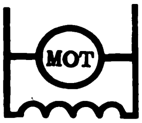


GENERATOR

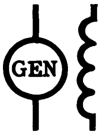
TYPES OF WINDINGS



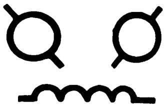
SERIES



SHUNT

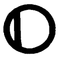


SEPARATELY EXCITED

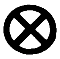


DYNAMOTOR

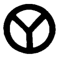
WINDING SYMBOLS



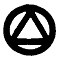
SINGLE-PHASE



TWO - PHASE

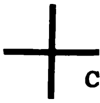


THREE-PHASE (WYE)

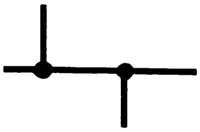


THREE-PHASE (DELTA)

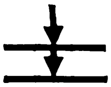
PATH, TRANSMISSION



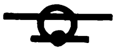
CROSSING NOT CONNECTED



JUNCTION CONNECTED



TWISTED PAIR

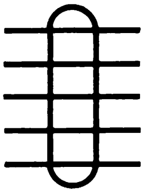


COAXIAL

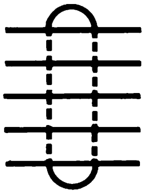
Figure VI-3

PATH, TRANSMISSION

CABLES



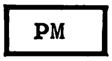
FIVE-CONDUCTOR CABLE



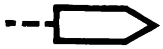
SHIELDED FIVE-CONDUCTOR CABLE

NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY

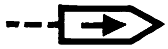
PERMANENT MAGNET



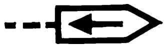
PICKUP HEAD



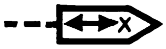
GENERAL



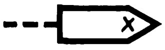
WRITING; RECORDING; HEAD, SOUND RECORDER



READING; PLAYBACK; HEAD, SOUND REPRODUCER



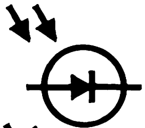
APPLICATION: WRITING, READING, AND ERASING



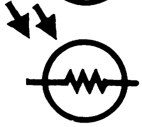
ERASING; ERASER, MAGNETIC

PHOTOELECTRIC CELLS

ASYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER

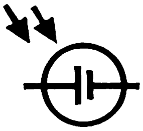


SYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER

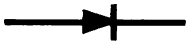


PHOTOELECTRIC CELLS (CONT.)

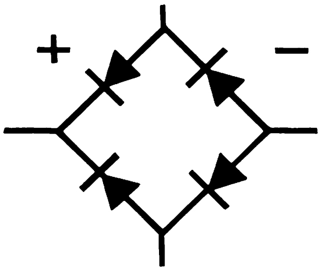
PHOTOVOLTAIC TRANSDUCER;
BARRIER PHOTOCELL;
BLOCKING-LAYER CELL;
SOLAR CELL



RECTIFIERS

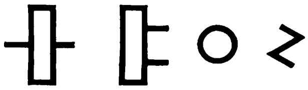


SEMICONDUCTOR DIODE; METALLIC RECTIFIER; ELECTROLYTIC RECTIFIER; ASYMMETRICAL VARISTOR
THE TRIANGLE IN THIS CASE SHALL BE FILLED.

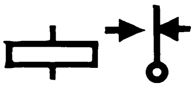


FULL WAVE BRIDGE TYPE

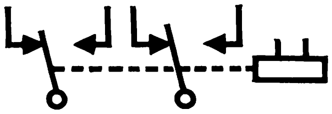
RELAYS



RELAY COIL

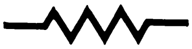


RELAY WITH TRANSFER CONTACTS (SPDT)

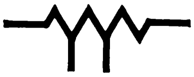


DOUBLE POLE, DOUBLE THROW (DPDT) RELAY

RESISTORS



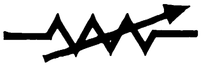
GENERAL

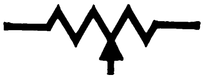


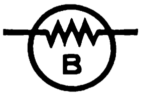
TAPPED

Figure VI-4

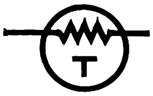
RESISTORS (CONT.)


VARIABLE

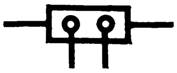

ADJUSTABLE

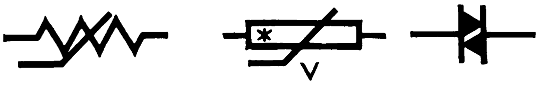


BALLAST LAMP



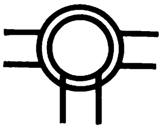
THERMISTOR

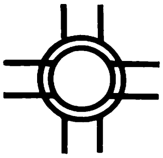

INSTRUMENT OR
RELAY SHUNT



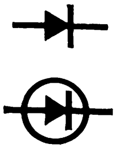
SYMMETRICAL VARISTOR
RESISTOR, VOLTAGE SENSITIVE
(SILICON CARBIDE, ETC.)

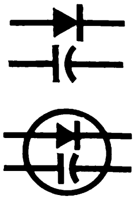
RESOLVER (SYNCHRO)


SINGLY-WOUND
ROTOR

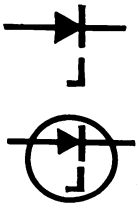

DOUBLY-WOUND
ROTOR

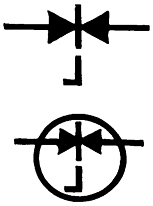
SEMICONDUCTOR DEVICE


SEMICONDUCTOR DIODE
SEMICONDUCTOR RECTIFIER DIODE

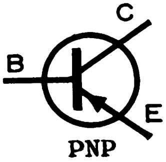

CAPACITIVE DIODE (VARACTOR)

SEMICONDUCTORS (CONT.)

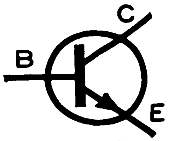

BREAKDOWN DIODE, UNIDIRECTIONA
(ALSO BACKWARD DIODE)


BREAKDOWN DIODE, BIDIRECTIONAL

SEMICONDUCTOR DEVICE, TRANSISTORS

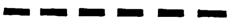


PNP

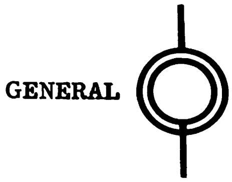


NPN

SHIELDING


SHORT DASHES. NORMALLY
USED FOR ELECTRIC OR MAGNETIC
SHIELDING

SYNCHROS

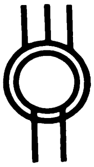


A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

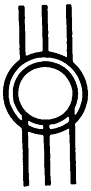
TX - TORQUE TRANSMITTER
TDX - TORQUE DIFFERENTIAL TRANSMITTER
CX - CONTROL TRANSMITTER
CDX - CONTROL DIFFERENTIAL TRANSMITTER
TR- TORQUE RECEIVER
CT - CONTROL TRANSFORMER

Figure VI-5

SYNCHROS (CONT.)

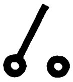


TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

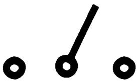


DIFFERENTIAL TRANSMITTER OR RECEIVER

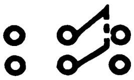
SWITCHES



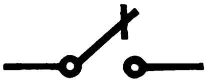
GENERAL
(SINGLE THROW)



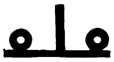
GENERAL
(DOUBLE THROW)



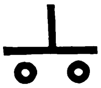
TWO-POLE
DOUBLE-THROW
SWITCH



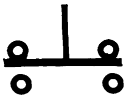
KNIFE SWITCH



PUSH BUTTON
(BREAK)

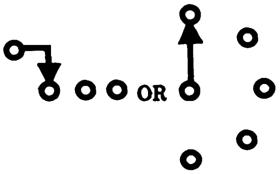


PUSH BUTTON
(MAKE)



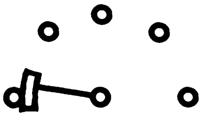
PUSH BUTTON TWO CIRCUIT

SELECTOR SWITCHES

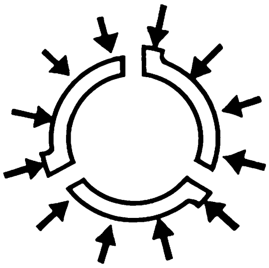


GENERAL
ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK-BEFORE-MAKE SWITCH.

MAKE-BEFORE
BREAK

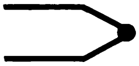


SELECTOR SWITCHES (CONT.)



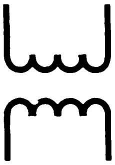
WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

THERMOCOUPLES

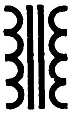


TEMPERATURE-MEASURING THERMOCOUPLE
(DISSIMILAR METAL DEVICE)

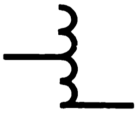
TRANSFORMERS



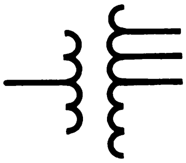
GENERAL



MAGNETIC CORE
TRANSFORMER



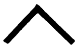
AUTOTRANSFORMER



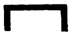
WITH TAPS,
SINGLE-PHASE

TUBES, ELECTRON

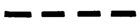
COMPONENT TUBE SYMBOLS



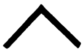
DIRECTLY-HEATED
(FILAMENTARY)
CATHODE



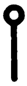
INDIRECTLY-HEATED
CATHODE



GRID



HEATER



COLD
CATHODE

Figure VI-6

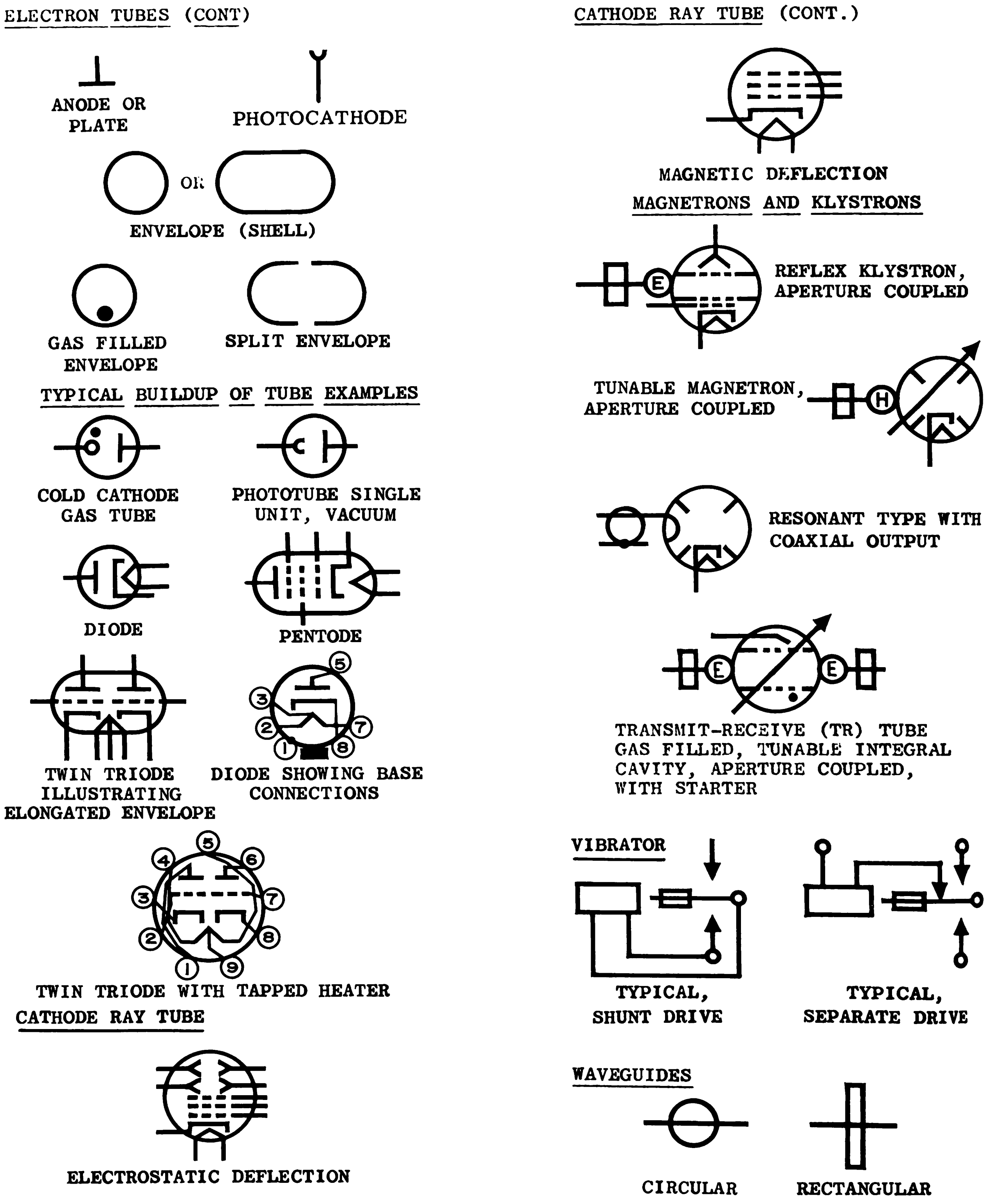
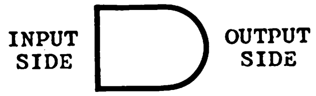

ELECTRON TUBES (CONT)
ANODE OR PLATE
PHOTOCATHODE
OR
ENVELOPE (SHELL)
GAS FILLED ENVELOPE
SPLIT ENVELOPE
TYPICAL BUILDUP OF TUBE EXAMPLES
COLD CATHODE GAS TUBE
PHOTOTUBE SINGLE UNIT, VACUUM
DIODE
PENTODE
TWIN TRIODE ILLUSTRATING ELONGATED ENVELOPE
5
3
2
7
1
8
DIODE SHOWING BASE CONNECTIONS
5
4
6
3
7
2
8
1
9
TWIN TRIODE WITH TAPPED HEATER
CATHODE RAY TUBE
ELECTROSTATIC DEFLECTION
CATHODE RAY TUBE (CONT.)
MAGNETIC DEFLECTION
MAGNETRONS AND KLYSTRONS
E
REFLEX KLYSTRON, APERTURE COUPLED
TUNABLE MAGNETRON, APERTURE COUPLED
H
RESONANT TYPE WITH COAXIAL OUTPUT
E
E
TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER
VIBRATOR
TYPICAL, SHUNT DRIVE
TYPICAL, SEPARATE DRIVE
WAVEGUIDES
CIRCULAR
RECTANGULAR

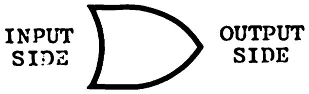
Figure VI-7

LOGIC SYMBOLS

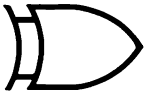
AND FUNCTION



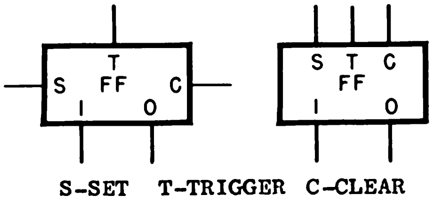
INCLUSIVE OR FUNCTION



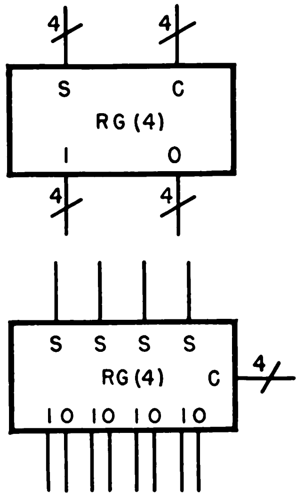
EXCLUSIVE OR FUNCTION



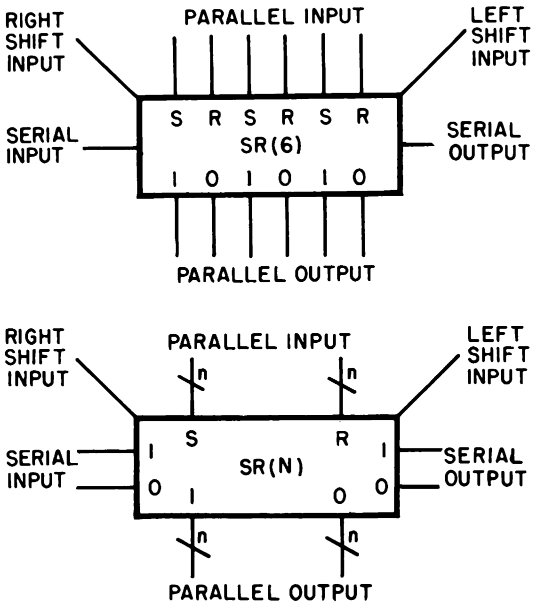
FLIP-FLOPS



BINARY REGISTER WITH 4 BIT CAPACITY



SHIFT REGISTER



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